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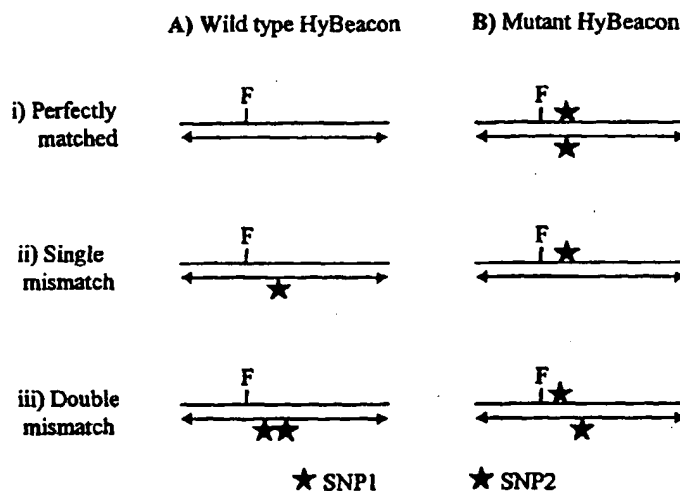
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(54) Title: **HYBRIDISATION BEACON AND METHOD OF RAPID SEQUENCE DETECTION AND DISCRIMINATION**

(57) Abstract: A method for detecting specific DNA sequences and discriminating single nucleotide polymorphisms (SNPs) using fluorescently labelled oligonucleotide probes is disclosed. Oligonucleotide probes are labelled with a reporter molecule preferentially attached to an internal nucleotide residue. The fluorescence emission of oligonucleotide probes varies significantly when in single-stranded and double-stranded states despite the absence of quencher moieties, allowing reliable detection of complementary DNA targets. The melting temperature of probe/target duplexes permits discrimination of targets that differ by as little as a single nucleotide residue, such that polymorphic targets may be discriminated by fluorescence quantitation and T_m . The hybridisation probes of this invention have been demonstrated to accurately identify homozygous and heterozygous samples using a single fluorescent oligonucleotide and direct investigation of saliva with hybridisation probes permits ultra-rapid genotypic analysis within 35-40 minutes. Target detection and SNP discrimination assays have been achieved in homogeneous, heterogeneous, 'real-time' and solid-phase formats.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

**HYBRIDISATION BEACON AND METHOD OF RAPID SEQUENCE
DETECTION AND DISCRIMINATION**

5 Introduction

A multitude of techniques for detecting specific DNA sequences and scoring known single nucleotide polymorphisms have been described. Several of these detection methods utilise hybridisation of fluorescently labelled probes and rely on the transfer of energy between donor and acceptor moieties. This invention embodies a new and simple fluorescent hybridisation probe detection system that does not rely on probe secondary structure or enzyme action. Interaction between these hybridisation probes and their target sequences generates significant alterations in fluorescence emission. Variations in hybridisation potential allow discrimination of polymorphic targets by the amount of fluorescence emission and the melting temperature of the probe/target duplexes.

Single Nucleotide Polymorphisms (SNPs) are the most abundant form of sequence variation in the human genome, occurring on average every thousand nucleotides. A SNP is a site within the DNA sequence that varies by a single base (substitution, insertion or deletion) from person to person. These SNPs may affect phenotypic characteristics directly, such as certain diseases, and are commonly employed as genetic markers to identify complex traits, such as response to medication (Pharmacogenetics). SNPs are extremely useful as genetic markers because they evolve slowly and are scored readily by a number of methods. Large-scale efforts are in progress to discover novel SNPs, for use in association studies that may allow identification of genes that contribute to common genetic disorders. Furthermore, many techniques have been developed to efficiently screen for known SNPs with a relatively high throughput. Current methods for SNP genotyping include restriction fragment length polymorphism (RFLP) analysis of polymerase chain reaction products (using gel electrophoresis

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for restriction fragment detection), allele-specific oligonucleotide (ASO) hybridisation, amplification refractory mutation system (ARMS), oligonucleotide ligation assay (OLA), single-strand conformation polymorphism (SSCP) analysis, chemical cleavage, heteroduplex analysis, mini-sequencing and a variety of probe based systems. Examples of probe based technologies include, molecular beacons, the 5'-exonuclease assay, hybridisation probes and Scorpion primers. Several of these probe systems rely on the transfer of energy between donor (e.g. fluorophore) and acceptor (e.g. quencher) moieties. Fluorescent probes are typically single-stranded oligonucleotides that exhibit lower amounts of fluorescence emission in isolation than when hybridised to target sequences. The structures of these probes convey high specificity, permitting the identification of targets that differ by as little as a single nucleotide.

The energy absorbed by a fluorophore may be transferred to a quencher and released as heat. Quenching of fluorescent signal may occur by Fluorescence Resonance Energy Transfer (FRET) or non-FRET mechanisms. FRET quenching requires a spectral overlap between the donor and acceptor, where the efficiency of quenching is related to the distance between the two moieties. Non-FRET quenching occurs through short-range 'contacts' between fluorophore and quencher, requiring no spectral overlap between moieties.

The 5'-exonuclease (TaqMan™) assay uses FRET quenching to analyse Polymerase Chain Reaction (PCR) amplified target DNA. TaqMan probes are oligonucleotides that contain fluorophore and quencher moieties preferably located on 5' and 3' termini. Very little fluorescence is emitted from intact probe due to efficient intra-molecular quenching. However, during PCR amplification, the probe specifically hybridises to its target sequence and the 5'-3'-exonuclease activity of *Taq* polymerase cleaves the probe between fluorophore and quencher moieties. Enzymatic cleavage of TaqMan™ probes spatially separates fluorophore and quencher components, causing significant increases in fluorescence

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emission correlated with target amplification. Careful design of TaqMan™ probes allows discrimination of polymorphic targets, where only perfectly matched probes are degraded to generate increases in fluorescence signal. Since TaqMan™ probes are digested during real-time PCR amplification, probes are not available for post-amplification melting curve analysis.

Molecular beacons are single-stranded oligonucleotide probes that are non-fluorescent in isolation, but become fluorescent upon hybridisation to target sequences. Non-hybridised molecular beacons form stem-loop structures, possessing a fluorophore covalently linked to one end of the molecule and a quencher linked to the other, such that the hairpin of the beacon places the fluorophore moiety in close proximity with the quencher. When molecular beacons hybridise to target sequences, fluorophore and quencher moieties become spatially separated, such that the fluorophore is no longer quenched and the molecular beacon fluoresces. Molecular beacons may be employed in end-point and 'real-time' assays for sequence detection and SNP discrimination. The secondary structure of the molecular beacon conveys high specificity to the hybridisation probe, allowing the identification of targets that differ by a single nucleotide. However, the molecular beacon's intra-molecular interaction potentially produces a source of competition for inter-molecular target hybridisation and, because the molecular beacon is an internal probe, it must compete with the amplicon's opposite strand for binding to the target sequence. The combination of both forms of competition may reduce molecular beacon hybridisation efficiency to some target molecules.

Hybridisation probes are oligonucleotides that are singly labelled with a fluorophore moiety. Two such oligonucleotides are required for each hybridisation probe assay, one labelled with a donor fluorophore and the other with an acceptor fluorophore. Fluorescein is commonly employed as the donor and Cy5, LC-RED 640 and LC-RED 705 are commonly used as acceptors. Excitation of the donor fluorophore produces an emission

spectrum that overlaps with the absorption spectrum of the acceptor fluorophore. Hybridisation probe pairs are designed to recognise adjacent nucleotide sequences within target molecules. In isolation, the acceptor oligonucleotide is not excited and does not generate a fluorescent signal.

5 However, during hybridisation to polynucleotide target sequences, the donor and acceptor probes are brought into close proximity, allowing fluorescence resonance energy transfer from the donor to the acceptor. Fluorescent signal from the acceptor fluorophore is only emitted when both probes are hybridised to the target molecule. When incorporated into PCR

10 reactions, fluorescence from the acceptor probe is monitored once per cycle of amplification, to facilitate real-time measurement of product accumulation, where the amount of fluorescence emitted by the acceptor is proportional to the quantity of target synthesised. Careful design of probes and assay conditions permits discrimination of closely related targets by

15 real-time PCR. Furthermore, pairs of hybridisation probes may be employed to discriminate alleles by melt peak analysis and T_m determination. Homozygous samples may be identified by the generation of specific melt peaks during melting curve analysis and heterozygous samples may be identified by the presence of two peaks within a single

20 melting trace.

5'-exonuclease, molecular beacon and hybridisation probe assays are bimolecular systems that have the probe and target sequences located on separate DNA strands. Scorpion probes operate through unimolecular binding events, where the probe and amplified target

25 sequence are located on the same DNA strand. Unimolecular binding events are kinetically favoured over bimolecular hybridisation. Scorpion probes comprise a primer with an attached probe tail sequence, where the probe sequence is contained within a stem-loop secondary structure similar to that of a molecular beacon. In the unextended form, Scorpion primers

30 are non-fluorescent due to fluorophore and quencher moieties being in close proximity. During PCR, the primer component of the Scorpion is

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extended at its 3' end producing the homologous target sequence required for probe hybridisation. When the Scorpion probe sequence hybridises to amplified target the fluorophore and quencher moieties become spatially separated generating significant increases in fluorescent signal concurrent with target amplification. Careful design of probes and assay conditions permits discrimination of polymorphic targets, where only perfectly matched targets produce increases in fluorescence signal during real-time PCR analysis.

TaqMan probes, molecular beacons, hybridisation probes and Scorpion primers utilise FRET to detect and discriminate polynucleotide sequences. However, the alternative light-up probe system does not require FRET transfer between donor and acceptor moieties to detect and discriminate DNA sequences. These light-up probes comprise a sequence recognising oligonucleotide and a single fluorescent reporter group, where the reporter is typically a derivative of the asymmetric cyanine dye thiazole orange. The fluorescent dye component of light-up probes is attached to the terminus of the oligonucleotide molecule. When single-stranded, probes emit significantly lower quantities of fluorescence than when hybridised to complementary nucleic acid sequences. By measuring the quantity of fluorescence emission, light-up probes may be employed to detect nucleic acid sequences and differentiate between targets differing by a single position.

Homogeneous assays, that perform target DNA amplification and sequence detection/discrimination in a single tube, have been described for molecular beacons, TaqMan probes (5' exonuclease assay), FRET probes and Scorpion primers. Homogeneous methods of analysis eliminate the requirement for downstream analysis (e.g. PCR product purification, enzyme digestion, gel analysis etc) to generate results and reduce the potential for cross-contamination between reactions.

The Invention

In one aspect the invention provides a hybridisation beacon (HyBeacon) which is an oligonucleotide possessing substantially no secondary structure and formed of nucleotide residues of which one is
5 labelled with a reporter and another is optionally labelled with a quencher, with preferably between 1 – 15 nucleotide residues between the reporter-labelled nucleotide residue and the quencher-labelled nucleotide residue. Hybridisation beacons possessing both fluorophore and quencher moieties are termed F-Q HyBeacons, whereas, probes that possess a reporter
10 component, such as a fluorophore, but lack a quencher moiety are termed F HyBeacons.

The hybridisation beacon of the invention is a linear single-stranded oligonucleotide possessing substantially no secondary structure. Secondary structure arises when one region of an oligonucleotide
15 hybridises with another e.g. forming a loop (as in conventional molecular beacons) which decreases the efficiency of the oligonucleotide hybridising with its complementary target. In the HyBeacons of this invention there is substantially no tendency for one region of the oligonucleotide to hybridise with another.

20 The length of the HyBeacon is such that it is suitable for hybridising with a complementary polynucleotide target, to provide a stable hybrid whose melting temperature depends on the exact sequence of the target. Oligonucleotides containing less than 15 nucleotide residues in certain cases do not form sufficiently stable hybrids, particularly where the
25 two hybridising sequences are not precisely complementary. Oligonucleotides which are longer than about 30 nucleotide residues in certain cases form hybrids whose melting temperature is relatively insensitive to the possible presence of a single nucleotide mismatch. Nucleotide residues are usually derived from the naturally occurring
30 nucleosides A, C, G and T. However nucleotide analogues may be used at one or more locations of the hybridisation beacon, such nucleotide

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analogues being modified e.g. in the base portion and/or the sugar portion and/or the triphosphate link. Base modifications, such as propynyl dU (dT-analogue) and 2-amino dA (dA analogue), generally alter the hybridisation properties and may make the use of oligonucleotides having less than 15
5 or more than 30 nucleotide residues attractive. Alternatively, oligonucleotides composed of or comprising peptide nucleic acid (PNA), locked nucleic acid (LNA), 2'-O-methyl RNA, phosphoramidate DNA, phosphorothioate DNA, methyl phosphonate DNA, phosphotriester DNA or DNA base analogues may be employed to form more stable interactions
10 with target sequences.

Both F and F-Q HyBeacons have been demonstrated to emit significantly greater amounts of fluorescence when hybridised to complementary nucleic acid sequences than when in the single-stranded conformation. An unexpected finding was that F HyBeacons emit
15 significantly more fluorescent signal when double-stranded than when in the single-stranded state despite the absence of a quencher component.

This is a significant finding in that it allows probe assays to be designed that do not require associated acceptor probes or energy transfer between probes as is required with known hybridisation probes. For the
20 purposes of this specification, such assays are termed "single probe assays".

Fluorophore-quencher systems are well described in the literature and will not be further described here. The preparation of oligonucleotides containing fluorophore-labelled nucleotide residues and
25 quencher-labelled nucleotide residues is also well described in the literature.

The signal ratio is the ratio of the signal intensity of a double-stranded hybrid comprising a hybridisation beacon to the signal intensity of the single-stranded probe and is preferably as large as possible, e.g. 3 or
30 more. This signal ratio is dependent upon multiple factors. For F-Q HyBeacons, the rate of energy transfer from an excited donor molecule

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(fluorophore) to a nearby acceptor molecule (quencher) depends, not only on the distance between the two moieties, but also on their relative angular disposition. HyBeacons with fluorophore and quencher moieties separated by as little as 1 or 3 nucleotide residues possess fluorescence signal ratios that are significantly and usefully greater than 1. HyBeacons possessing more than 3 nucleotides separating fluorophore and quencher exhibit larger signal ratios. For F-Q HyBeacons, fluorophore and quencher components are preferably positioned such that 5 or more nucleotide residues separate the two moieties. Donor and acceptor molecules separated by less than 5 nucleotides may make 'contact', permitting possible non-FRET interactions.

F HyBeacons have been demonstrated to exhibit comparable signal ratios to F-Q HyBeacons that possess more than 5 nucleotides separating the donor and acceptor components. Signal ratios in F HyBeacons are significantly and usefully greater than 1 despite the absence of quencher moieties. The absence of acceptor molecules causes F HyBeacons not to be influenced by angular disposition affects, such that the relative distance between fluorophore and quencher molecules cannot determine the amount of fluorescent signal emitted in double-stranded and single-stranded states. It is believed that fluorophore moieties emit significantly more fluorescent signal when HyBeacon probes are hybridised to target molecules than when the probes are in the single-stranded form possibly due to some form of interaction with duplex DNA.

In certain case, it may be appropriate to include more than one reporter in the oligonucleotide.

In a hybridisation beacon according to the invention, the oligonucleotide preferably has a sequence fully complementary to one allele of a known polynucleotide target having a known polymorphism, e.g. a point mutation or a single base insertion or deletion (SNP). In F-Q HyBeacons, this SNP of the target is preferably, though not essentially, complementary to a nucleotide residue of the hybridisation beacon intermediate between the fluorophore-labelled nucleotide residue and th

quencher-labelled nucleotide residue. For F HyBeacons, the site of polymorphism is preferably, though not essentially, located centrally within the oligonucleotide probe.

Alternatively, the hybridisation beacon may be
5 complementary to a known non-polymorphic polynucleotide target and may simply be used to detect that target. Also, the hybridisation beacons may be used to study potentially polymorphic targets with unknown and uncharacterised polymorphisms. The possibility is envisaged of mapping the position and/or nature of unknown polymorphisms by differential
10 beacon hybridisation and differences in melt peak T_m .

The fluorophore-labelled nucleotide residue and/or quencher-labelled nucleotide residues are preferably positioned internally within the oligonucleotide sequence, rather than at the 5'-end or the 3'-end. When the hybridisation beacon is caused to hybridise with a polynucleotide
15 target, all these features contribute to the formation of a stable hybrid with a optimal melting temperature and a substantial difference in melting temperatures between strands which are perfectly matched and strands which have a single or multiple positions of mismatch (ΔT_m).

It may be convenient to provide two or more hybridisation
20 beacons, one fully complementary to each allele of the SNP under investigation. Where each hybridisation beacon carries a different fluorophore, it may be convenient to mix the probes in solution for analysis of homozygous and heterozygous targets. In the same way, a mixture of hybridisation beacons complementary to the various alleles of several
25 different SNPs may be used together in solution for multiplex analysis, provided that each is labelled with a spectrally distinct fluorophore.

Alternatively, a hybridisation beacon of this invention may be provided immobilised on or within a support. Techniques and linkers for immobilising oligonucleotides using supports in forms that leave them free
30 to hybridise with complementary targets in solution are well described in the literature. Also included within the scope of the invention is an array of

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oligonucleotide probes immobilised at spaced locations using a support, wherein different oligonucleotide probes are different hybridisation beacons according to this invention. Furthermore, HyBeacon probes may be employed to analyse DNA targets immobilised on or within a support, where distinct targets may be positioned at spaced locations on array type formats.

In another aspect, this invention provides a method of investigating a polynucleotide target which optionally has a known or suspected polymorphism, which method comprises providing an oligonucleotide probe comprising a fluorophore-labelled nucleotide residue and, optionally, a quencher-labelled nucleotide residue. The polynucleotide target is incubated with the oligonucleotide probe to form a hybrid, the oligonucleotide probe exhibiting a higher level of fluorescence when in the form of the hybrid than when in single-stranded form. The level of fluorescence emitted by the oligonucleotide probe is observed at a predetermined temperature, or monitored over a range of temperatures. Preferably the oligonucleotide probe is a hybridisation beacon as herein defined. In a preferred embodiment of the invention, the method utilises a single type of hybridisation beacon according to the invention without an associated quencher, and without a further probe carrying an acceptor moiety.

The polynucleotide target may be DNA, RNA or cDNA, and is used in single-stranded form, or a DNA duplex may be probed to form a triplex. The polynucleotide target has a known polymorphism, preferably a SNP. The target is incubated under hybridising conditions with an oligonucleotide probe, which may be a hybridisation beacon as herein described. It is necessary that the hybrid generate a stronger fluorescence signal than the single-stranded oligonucleotide probe. The melting temperature of the hybrid will depend, amongst other things, on whether the polynucleotide target and oligonucleotide probe are fully complementary or whether there is a single or even a double mismatch

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arising at or close to the location of the SNP. The method involves observing the level of fluorescence signal, emitted by the oligonucleotide probe, at a predetermined temperature near the melting temperature of the hybrid, or over a range of temperatures. Two alternatives are described, although others are possible:-

- a) The temperature of a solution containing the hybrid is slowly raised, while continuously observing a fluorescence signal, in order to construct a graph of negative derivative of fluorescence signal intensity with respect to temperature ($-dF/dT$) against temperature. The melting temperature (T_m) of the hybrid appears as a peak, and provides information about the sequence of the polynucleotide target. The T_m s generated through HyBeacon melting analysis may be used to distinguish polymorphic targets. The range of temperature chosen generally encompasses the melting temperature of the hybrid.
- b) A solution of the hybrid is held at a predetermined temperature and the level of fluorescence observed. Generally, the predetermined temperature is chosen to be intermediate between the melting temperature of a perfectly matched hybrid and the melting temperature of a hybrid with one or two mismatches. The level of fluorescence signal observed provides an indication of whether or not the hybrid has melted, and so provides information about the sequence of the polynucleotide target. Polymorphic targets may be distinguished in end-point and real-time or kinetic formats.

Typically, the hybridisation beacon has a sequence complementary, typically fully complementary, to one allele of the target polynucleotide. Use of fully complementary beacons allows differentiation between matched and mismatched hybridisation. Suitably, each of two or more different hybridisation beacons has a sequence complementary, ideally fully complementary, to a different allele of the target polynucleotide.

Conveniently, the polynucleotide target may be a PCR amplicon, formed by using suitable primers to amplify a desired portion of

genomic DNA. It may be convenient to perform the amplification and target investigation in a homogenous mode, e.g. in a single reaction vessel by adding the oligonucleotide probe before, during or after the amplification cycling procedure. It may also be convenient to perform target
5 amplification and sequence investigation directly from samples, such as saliva, without prior extraction of DNA, RNA or cDNA. Preferably the oligonucleotide probe is modified at its 3'-end so as to prevent chain extension during PCR amplification.

The melting temperatures of hybridisation beacons may be used to
10 identify polymorphic target polynucleotides. The hybridisation beacons of the invention may also be employed to identify homozygous and heterozygous DNA using a single probe.

The following examples illustrate the invention and are not intended to be limiting in any way.

15

FIGURE 1: Differential HyBeacon Hybridisation. Illustrates the difference between matched, mismatched and double mismatched interactions, where stars represent single nucleotide polymorphisms (SNPs). Type A interactions involve a HyBeacon molecule designed to be
20 perfectly matched to a wild type target or one allele of an SNP. Type B interactions involve a HyBeacon molecule designed to be perfectly matched to a mutant target or the alternate allele of the SNP. When considering two independent SNPs, beacon hybridised to target molecule may be either (i) perfectly matched, (ii) possess a single base mismatch or
25 (iii) possess multiple base mismatches.

FIGURE 2: SNP discrimination using the amount of fluorescence. The B9414 HyBeacon was hybridised to perfectly matched (i) and single base mismatched oligonucleotides (ii) and was also studied in the absence of
30 target (iii). a) Melting profiles derived from the B94141 HyBeacon. At temperatures below 42°C and above 52°C, the amount of fluorescence

emitted by probe hybridised to matched and mismatched targets is very similar. However, between these temperatures the quantity of fluorescence emitted by fully complementary probe is significantly greater than the fluorescence emission of the mismatched HyBeacon. b) Reactions were
5 denatured and rapidly cooled to 46°C for fluorescence acquisition. Significant clustering within treatments and statistical differences between treatments are observed, such that probe hybridised to a matched target emits significantly more fluorescence than HyBeacon hybridised to a mismatched target, which in turn emits more fluorescence than
10 hybridisation beacon in the absence of target. c) HyBeacon in the absence of target does not generate melting peaks. B9414 produces melting curves possessing Tms of approximately 52°C and 44°C in the presence of matched and mismatched targets respectively, allowing reliable discrimination of SNPs.

15

FIGURE 3: Comparison of F and F-Q HyBeacon probes. The NAT2 hybridisation beacons F17834 (F-Q) and 0203002 (F) were hybridised to a perfectly matched oligonucleotide. F and F-Q HyBeacons possess identical nucleotide sequence and generate high quality peaks with Tms of
20 approximately 60°C in melting analyses. Due to the lack of a quencher moiety, F HyBeacons emit larger amounts of background fluorescence compared with F-Q probes.

FIGURE 4: Melting analysis of InDel polymorphisms. The TB0993 NAT2 *4 probe was hybridised to a series of oligonucleotide targets to
25 determine whether hybridisation beacons have the potential to discriminate insertion and deletion polymorphisms. Matched target (M), 3 oligonucleotides containing single nucleotide insertions (1-3) and 3 oligonucleotides containing single nucleotide deletions (4-6) were
30 compared. Melting analysis was performed for each HyBeacon/target duplex. In all cases, matched probe generated melting curves with higher

Tms than the mismatched InDel reactions, such that SNPs may be discriminated on the basis of melt peak Tm. a) Insertion Oligonucleotides. b) Deletion oligonucleotides. c) Demonstrates that SNPs may also be discriminated on the basis of amount of fluorescence emission, where
5 matched beacon emits more fluorescence than hybridisation to all InDel mismatches.

FIGURE 5: Discrimination of SNPs in a heterogeneous format. F and F-Q HyBeacon probes were employed to discriminate targets containing
10 the *CYP2D6* *3 polymorphism, where the DNA targets employed were isolated 119bp PCR products. F (2D63B) and F-Q (2D63A) probes are identical nucleotide sequences, being perfectly matched to the *1 allele of the *CYP2D6* gene and possessing a single base mismatch when hybridised to the *3 allele. a) The 2D63A F-Q probe generates melt peaks
15 with Tms of approximately 65°C and 56°C when hybridised to matched and mismatched targets respectively. b) The 2D63B F HyBeacon produces melt peaks with Tms of approximately 65°C and 58°C when hybridised to *1 and *3 PCR targets respectively.

20 **FIGURE 6: Homogeneous detection of DNA sequences.** Detection of *CYP2D6**1 sequence in genomic DNA (1) and saliva (2) samples using the 2D64C* HyBeacon probe to monitor the real-time accumulation of PCR product. The amount of fluorescence emitted from HyBeacon probes is correlated with the amplification of specific target sequences. Control
25 reactions (3) that do not contain template DNA or amplified product also do not display elevated levels of fluorescence emission during PCR.

FIGURE 7: Discrimination of SNPs in a homogeneous format. The F HyBeacon probe 0203002, which is perfectly matched to *NAT2* *4
30 sequence, was employed to discriminate *4 and *5A SNPs in homogeneous LightCycler assays. a) SNPs were reliably discriminated

through 'real-time' PCR amplification, where only reactions containing the matched *4 template produced significant increases in fluorescence emission. b) SNPs were also discriminated post-amplification by melting analysis, where matched *4 alleles generated melt peaks with significantly higher Tms than mismatched *5A target sequences. End-point analysis of amplified products permits validation of 'real-time' data.

FIGURE 8: Real-time discrimination of the *CYP2D64 polymorphism:** The 2D64C* HyBeacon was employed to detect and discriminate the *1 and *4 alleles of the *CYP2D6* gene. Polymorphic sequences were amplified from pGEM-T plasmids containing the *1 allele (1), and the *4 allele (2). A mixture of *1 and *4 plasmids was employed to simulate heterozygous DNA (3). No template control reactions (C) were also included in the analysis. Only those reactions that contain the *1 allele (i.e. samples 1 & 3) generate increases in fluorescence emission during real-time PCR amplification. Homozygous *4 samples and no template controls do not produce elevated fluorescent signals. Samples that are heterozygous for *1 and *4 alleles cause intermediate quantities of fluorescence to be generated during amplification.

FIGURE 9: Discrimination of *CYP2D6* *1 and *4 alleles by melt peak analysis. Polymorphic targets were amplified from genomic DNA samples and the melt peaks displayed here were derived from post-amplification analysis of samples 1 (homozygous *4), 2 (homozygous *1) and 3 (heterozygous DNA). The 2D64C* HyBeacon is fully complementary to the *1 allele of the *CYP2D6* gene and generates single melt peaks possessing Tms of 49°C and 60°C with homozygous *4/*4 and *1/*1 samples respectively. Heterozygous samples, possessing both *4 and *1 alleles, generate traces possessing 49°C and 60°C melt peaks.

FIGURE 10: Identification of heterozygosity using F-Q HyBeacons.

Two F-Q HyBeacons, perfectly matched to both alleles of an SNP were required to distinguish homozygous samples (containing only one allele of a polymorphism) from heterozygous samples (containing both alleles). The

5 F17834 and F17835 HyBeacons are perfectly matched to *4 and *5A alleles of the *NAT2* gene respectively. F17834 and F17835 possess significantly different Tms to distinguish the two FAM labelled probes. a) F17834 generates melting peaks possessing Tms of approximately 60°C and 54°C in the presence of homozygous *4 and *5A alleles respectively.

10 b) F17835 generates melting peaks possessing Tms of approximately 52°C and 49°C in the presence of homozygous *5A and *4 alleles respectively. c) Reactions containing F17834 or F17835 HyBeacons produce only matched melting peaks in the presence of heterozygous DNA. Reactions containing both probes produce melting traces possessing Tms of

15 approximately 59°C and 52°C in the presence of a mixture *4 and *5A alleles. The presence of two peaks within a single melting trace allows identification of heterozygous samples.

FIGURE 11: Analysis of heterozygosity using an F HyBeacon. The

20 HyBeacon DdeFL1, which is perfectly matched to the *NAT2* *5C polymorphic sequence, was used to test the potential of F HyBeacons to discriminate heterozygous samples. a) Homozygous samples analysed with DdeFL1 generate melting traces possessing a single peak. The DdeFL1 probe was hybridised to homozygous *5C and *4 PCR targets, in

25 heterogeneous assays, generating 54°C and 47°C melting curves respectively. b) Reactions containing the DdeFL1 HyBeacon and a mixture of matched and mismatched targets generate curves possessing both the 54°C and 47°C peaks in the same melting trace. The presence of two peaks in a melting trace permits identification of heterozygous samples.

FIGURE 12: The limitations of HyB acon multiplex analysis. To examine the potential for HyBeacon multiplex analysis, the 2D64B HyBeacon probe was included in reactions containing both specific and non-specific PCR templates. PCR templates comprised a mixture of specific (*CYP2D6*) and non-specific (*NAT2*) DNA, such that the proportion of specific template was varied between 100% and 5%. a) Reactions contained *CYP2D6* primers but lacked *NAT2* primers, such that only specific targets were produced. A small variation in crossing-point was observed as the concentration of specific target was reduced. However, amplification and detection efficiencies were comparable between reactions. b) Reactions contained *CYP2D6* and *NAT2* primers, such that specific and non-specific targets were generated. Significant reductions in amplification and detection efficiencies were observed as the proportion of specific target was reduced. However, results suggest that multiplex reactions containing up to 4 or 5 targets may be possible.

FIGURE 13: Multiplex HyBeacon analysis. a) *NAT2* *4 and *CYP2D6* *1 targets were simultaneously amplified and detected in a single microtitre plate well using FAM (BamFL1) and HEX (2D64E) labelled probes respectively. Only reactions containing genomic DNA and sequences fully complementary to HyBeacon probes displayed elevated levels of fluorescence emission throughout amplification. Negative control reactions did not generate increases in fluorescence emission. b) Melt peaks were derived from FAM, HEX and TET labelled probes using the ABI PRISM 7700 instrument and an Excel macro. Melt peaks displayed here were derived from probe hybridisation to complementary oligonucleotides.

FIGURE 14: The effect of $MgCl_2$ concentration on HyBeacon T_m . The hybridisation beacon F17834 was hybridised to a fully complementary oligonucleotide in a series of $MgCl_2$ concentrations, varying from 0mM to 50mM. The T_m of the hybridisation beacon has been demonstrated to

increase as the MgCl_2 concentration rises. a) Illustrates the hybridisation beacon melt curves derived from reactions containing: 0mM, 0.001mM, 0.005mM, 0.01mM, 0.05mM, 0.1mM, 0.2mM, 0.3mM, 0.4mM, 0.5mM, 0.6mM, 0.7mM, 0.8mM, 0.9mM, 1mM, 1.5mM, 2mM, 3mM, 4mM, 5mM, 7mM, 10mM and 50mM MgCl_2 (left to right respectively). b) Demonstrates the positive correlation that exists between MgCl_2 concentration and HyBeacon T_m . When the T_m of the hybridisation beacon is plotted against the log of MgCl_2 concentration, a linear relationship is observed within a defined concentration range (in this case between 0.1mM and 10mM). Linear regression analysis performed on this data set generated an R^2 value of 99.4%.

FIGURE 15: Generation of a HyBeacon PCR buffer – The affect of BSA. Displays the real-time PCR data and post-amplification melt results derived from a series of PCR buffers, using a NAT2 *5A HyBeacon (NAT2*5) to monitor target amplification. A range of BSA concentrations were added to a PCR buffer designed for HyBeacon analysis: 1) 0ng/ μl , 2) 1ng/ μl , 3) 2.5ng/ μl , 4) 5ng/ μl , 5) 7.5ng/ μl and 6) 10ng/ μl . TaKaRa Z-Taq PCR buffer (7) was also analysed for comparison. Concentrations of BSA greater than 2.5ng/ μl enhance the efficiency of target amplification and detection in real-time analyses, such that the magnitude of the fluorescence increase is superior to TaKaRa buffer in this instance. The quality of melt peaks derived from HyBeacon analysis is superior in the lower concentrations of BSA. The higher concentrations of BSA decrease melt quality by generating peak 'shoulders' and increasing peak width. The optimal concentration of BSA in real-time and post-amplification analyses appears to be between 2.5ng/ μl and 5ng/ μl .

FIGURE 16: SNP discrimination efficiency and amplicon size. The size and position of target amplicons has been demonstrated to have significant affects on the efficiency of homogeneous and heterogeneous HyBeacon

SNP assays. Two sets of primers, amplifying *NAT2* *4 products (flanking the *6 SNP) differing in size by 22bp, were compared in heterogeneous melting curve analysis experiments. a) The 103bp *NAT2* product, amplified from TaqF and TaqR primers, does not generate any melt peaks in
5 heterogeneous assays containing the F17836 HyBeacon. b) However, the 81bp *NAT2* *4 product, amplified from TaqF2 and TaqR2 primers, does generate matched and mismatched melting curves with the F17836 probe. 103bp and 81bp samples were both detected on agarose gels, confirming that the dissimilarity between amplicons is due to variations in probe
10 hybridisation and not to differences in amplification efficiency.

FIGURE 17: SNP discrimination using asymmetric target amplification. The efficiencies of HyBeacon mediated target detection and SNP discrimination were compared in symmetric and asymmetric PCR
15 assay formats. Both types of PCR amplification only generate increases in fluorescence signal in the presence of matched target. Eight HyBeacons were compared; four of which displayed equivalent efficiencies between symmetric and asymmetric amplification methods (data not shown). a) The F17836 HyBeacon probe possessed a significantly reduced detection
20 efficiency when employed in asymmetric assays. b) Whilst three other HyBeacons displayed greater amounts of fluorescence increase by asymmetric amplification compared with that generated by symmetric amplification (as demonstrated by the 2D64B probe).

25 **FIGURE 18: SNP discrimination using hybridisation beacons and the DASH instrument.** The hybridisation beacon F17832, which is fully complementary to the *NAT2* *4 allele of the *5A polymorphism, was used to discriminate *4 and *5A polymorphic targets immobilised on a solid phase. The hybridisation beacon is fully complementary and mismatched when
30 hybridised to *4 and *5A sequences respectively. Matched and mismatched hybridisation generates melting curves possessing Tms of

- 20 -

approximately 66°C and 60°C respectively. Establishing matched and mismatched zones for the hybridisation beacon allows automatic classification of samples using the DASH software.

5 **FIGURE 19: SNP discrimination using DNA polymerases lacking 5'-3'-exonuclease activity.** NAT2 *4 and *5A alleles were amplified with DNA polymerases that possess (*Taq*) and lack (Deep Vent and Stoffel fragment) 5'-3' exonuclease activity, to examine whether F HyBeacon probe digestion is required to generate increases in fluorescence emission. The

10 F HyBeacon 0203002 was used to detect amplification and discriminate SNPs. a) Comparison of *Taq* (1) and Deep Vent (2) polymerases amplifying the fully complementary *4 sequence. Both polymerases generate 'real-time' increases in fluorescence emission with the matched template whilst reactions containing mismatched *5A template do not

15 produce increases in fluorescence emission (3). b) Comparison of *Taq* (1) and Stoffel fragment (2) polymerases amplifying the fully complementary *4 allele. Both polymerases generate 'real-time' increases in fluorescence emission in the presence of matched *4 template but reactions containing only the mismatched *5A allele do not produce increases in fluorescence

20 emission (3).

FIGURE 20: 'Real-time' quantitative PCR using a HyBeacon probe. a) 'Real-time' homogeneous assays were performed using the 2D64B HyBeacon to monitor amplification of a *CYP2D6* sequence. A range of

25 known DNA concentrations were analysed: 1) 41.5×10^9 attograms per microlitre (ag/μl), 2) 41.5×10^8 ag/μl, 3) 41.5×10^7 ag/μl, 4) 41.5×10^6 ag/μl, 5) 41.5×10^5 ag/μl, 6) 41.5×10^4 ag/μl, 7) 41.5×10^3 ag/μl, 8) 41.5×10^2 ag/μl and 9) 415 ag/μl. Crossing points were measured for each DNA concentration. b) Standard curves were constructed by plotting Log DNA

30 concentration against crossing-point. Standard curves were used to quantify DNA concentrations present in 'unknown' reaction samples.

FIGURE 21: Homogeneous real-time saliva analysis. Detection and discrimination of NAT2 *4 and *5C polymorphic targets were performed by real-time PCR and melting analysis methodologies. The DdeFL1 HyBeacon, which is fully complementary to the *5C allele of the NAT2 gene, was used to genotype three saliva samples (1, 2 & 5). A no template control reaction (C) was also included in the analysis. a) Increases in fluorescent signal are only generated in homogeneous PCR reactions in the presence of the *5C allele. Therefore, reactions that are homozygous and heterozygous for the *5C allele (i.e. samples 1 & 5 respectively) generate significant increases in fluorescent signal, whilst reactions homozygous for the *4 allele (sample 2) do not produce increases in fluorescent signal. Heterozygous samples, possessing both *5C and *4 alleles, cause intermediate quantities of fluorescence to be generated during amplification. b) The DdeFL1 probe generates single melt peaks, possessing Tms of 47.6°C and 54.1°C, when hybridised to homozygous *4 and *5C DNA respectively. Heterozygous samples generate traces possessing both 47.6°C and 54.1°C melt peaks, whilst reactions that lack target DNA do not generate either peak.

FIGURE 22: HyBeacon melting peak analysis of saliva amplified DNA. The DdeFL1*4 HyBeacon, which is fully complementary to the *4 allele of the NAT2 gene, was employed to genotype saliva samples with respect to the *5C polymorphism. a) Saliva sample 1 is homozygous for the *5C allele since HyBeacon hybridisation results in a single mismatched melt peak possessing a Tm of 42.6°C. b) Saliva sample 3 is heterozygous for *5C and *4 alleles since two peaks are generated during melting analysis. c) Saliva sample 2 is homozygous for the *4 allele since probe hybridisation produces a single matched melt peak possessing a Tm of 52.6°C.

FIGURE 23: RFLP saliva analysis. Restriction Fragment Length

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Polymorphism analysis was performed for NAT2 *4 and *5C PCR products amplified from saliva samples. Lane M is a 10bp ladder (GIBCO BRL). Restriction enzyme digestion permits samples 1-3 to be typed as *5C/*5C, *4/*4 and *4/*5C respectively.

5

Materials and Methods

(i) Hybridisation beacon design.

HyBeacon probes were designed to hybridise to ten SNPs located in the human *N-acetyltransferase 2* (NAT2) gene (see table 1) and the cytochrome P450 encoding (*CYP*) genes (see tables 2 and 3). Probes were designed such that polymorphic nucleotides are positioned towards the centre of HyBeacon sequences. All HyBeacon probes are approximately 20 nucleotides in length and possess fluorophore moieties linked to internal uracil residues (replacing thymine in DNA sequences).

15 The fluorescent dyes 6-carboxyfluorescein (FAM), tetrachlorofluorescein (TET) and hexachlorofluorescein were attached to U residues by novel chemistries (available from Oswel DNA services, Southampton, UK) and six fluorophore linkage chemistries (FAM propo dU, FAM propargyl dU, dU C6 FAM, dU FAM, FAM cap prop dU and FMOC dU) were evaluated. The

20 dU C6 FAM and FMOC dU fluorophores were found to generate slightly superior data and were used preferentially. In F-Q HyBeacons, quencher moieties (Methyl Red) were also positioned on internal U residues, where HyBeacons with 1, 3, 5, 6, 7, 8 and 9 nucleotide residues separating fluorophore and quencher molecules have been tested. F-Q HyBeacons

25 possessing fluorophore and quencher molecules flanking and non-flanking the polymorphic nucleotide were investigated. The majority of HyBeacons synthesised possess a 3' phosphate or octanediol component to prevent *Taq* mediated extension from HyBeacons when the probes are incorporated into real-time PCR assays. F and F-Q HyBeacons were

30 designed to be perfectly matched to one allele of NAT2 and CYP polymorphic sequences, such that the other variant of an SNP created a

position of mismatch upon probe hybridisation. HyBeacon probes, fully complementary to both alleles, were synthesised for each biallelic SNP.

Table 1

```

1  ATGGACATTG AAGCATAATTT TGAAAGAATT GGCTATAAGA ACTCTAGGAA CAAATTGGAC
61 TTGGAACAT TAAC TGACAT TCTTGAGCAC CAGATCCGGG CTGTTCCCTT TGAGAACCTT
121 AACATGCATT GTGGGCAAGC CATGGAGTTG GGCTTAGAGG CTATTTTGA TCACATTGTA
181 AGAAGAAACC GGGGTGGTG GTGTCTCCAG GTCATCAAC TTCTGTACTG GGCTCTGACC
241 ACAATCGTT TTCAGACCAC AATGTTAGGA GGGTATTTT ACATCCCTCC AGTTAACAA
301 TACAGCACTG GCATGGTTCA CCTTCTCCTG CAGGTGACCA TTGACGGCAG GAATTACATT
361 GTCGATGCTG GGTCTGGAAG CTCCTCCAG ATGTGGCAGC CTCTAGAAAT AATTTCTGGG
421 AAGGATCAGC CTCAGGTGCC TTGCATTTTC TGCTTGACAG AAGAGAGAGG AATCTGGTAC
481 CTGGACCAA TCAGGAGAGA GCAGTATATT ACAACAAAG AATTTCTTAA TTCTCATCTC
541 CTGCCAAAGA AGAACACCA AAAATATAC TTATTTACGC TTGAACCTCG AACAAATTGAA
601 GATTTTGAGT CTATGAATAC ATACCTGCAG ACGTCTCAA CATCTTCATT TATAACCACA
661 TCATTTTGTT CCTTGCAGAC CCGAGAAGG GTTTACTGTT TGGTGGGCTT CATCCTCACC
721 TATAGAAAT TCAATTATA AGACAATACA GATCTGGTCG AGTTTAAAC TCTCACTGAG
781 GAAGAGGTTG AAGAAGTGCT GAAAATATA TTTAAGATTT CCTTGGGGAG AAATCTCGTG
841 CCCAAACCTG GTGATGGATC CCTTACTATT TAGAATAAGG AACAAATAA ACCCTTGTGT
901 ATGTATCACC CAACTCACTA ATTATCAACT

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The NAT2 polymorphic sequence. Sequence of the human gene for arylamine N-acetyltransferase 2 (NAT2).

Positions containing single nucleotide polymorphisms (SNPs) are shown in bold type. Restriction fragment length polymorphisms exist of positions 481 (*5A), 590 (*6), 803 (*5C) and 857 (*7A).

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(ii) *Amplification of NAT2 and CYP2D6 polymorphic PCR products.*

Polymorphic targets were amplified from either saliva (diluted to 50% with water), genomic DNA isolated from reference blood samples (University of Dundee), human placental genomic DNA (Sigma-Aldrich) or
5 pGEM-T plasmids (Promega) containing amplified *NAT2* and *CYP* products. Various primer pairs, generating *NAT2* and *CYP* amplicons differing in size and position relative to the polymorphic sites, were evaluated. For example, the optimal primer pairs used to amplify the *NAT2**5A, *NAT2**5C, *NAT2**6, *NAT2**7A, *CYP2D6**3 and *CYP2D6**4
10 polymorphic sequences were 195991/195993, DdeF2/DdeR, TaqF2/TaqR2, BamF2/BamR, 2D63F/2D63R and 2D64F2/2D64R2 respectively (table 4). Standard polymerase chain reaction (PCR) was performed to amplify DNA fragments of approximately 80-150bp that contained the polymorphic nucleotides. Target detection and SNP
15 discrimination assays were performed in heterogeneous and homogeneous formats.

20

25

30

TABLE 2. The nucleotide sequences of F-Q HyBeacon probes designed for NAT2 (*5A, *5C, *6 and *7A) and CYP2D6 (*3 and *4) polymorphisms. FAM fluorophore (5) and quencher (6) moieties were linked to internal uracil residues by novel chemistries. The majority of oligonucleotide probes were end-blocked using a 3'-phosphate (3P).

5

HyBeacon	Description	Sequence (5' → 3')
B9412	FAM propo dU, NAT2 *5A	GAATCTGGTA5C6GGACCAA
B9413	FAM propo dU, NAT2 *5A	GAATCTGG5ATC6GGACCAA
B9414	FAM propo dU, NAT2 *5A	GAATC5GGTATC6GGACCAA
TB0993	FAM propargyl dU, NAT2 *5A	GAATC5GGTACC6GGACCAA3P
TB0994	FAM propargyl dU, NAT2 *5A	GAATC5GCTACC6GGACCAA3P
F17830	dU C6 FAM, NAT2 *5A	GATTTGGTCCAGG5ACCAGA6TC3P
F17831	dU FAM, NAT2 *5A	GATTTGGTCCAGG5ACCAGA6TC3P
F17832	dU C6 FAM, NAT2 *5A	GAT5TGGTCCAGG6ACCAGATTC3P
F17833	dU FAM, NAT2 *5A	GAT5TGGTCCAGG6ACCAGATTC3P
F17834	dU C6 FAM, NAT2 *5A	GAGAGGAATC5GGTACC6GGACC3P
F17835	dU C6 FAM, NAT2 *5A	GAATC5GGTACT6GGACCAA3P
F17836	dU C6 FAM, NAT2 *5A	C5TGAACC6CGAACAATTGAAG3P
F17837	dU C6 FAM, NAT2 *5A	CTTGAACC5CGAACAAT6GAAG3P
F17838	dU C6 FAM, NAT2 *6	CTTGAACC5CGAACAAT6GAAG3P
F17839	dU C6 FAM, NAT2 *6	CTTCAATTG5TCGAGG6TCAAG3P
F17840	dU C6 FAM, NAT2 *6	CTTCAA5TGTTTCGAGG6TCAAG3P
TaqFLA	dU C6 FAM, NAT2 *6	CTTCAA5TGTTTGAGG6TCAAG3P
F17847	dU C6 FAM, NAT2 *5C	GAAGTGC5GAGAAA6ATATTTAAG3P
F18140	dU propargyl FAM, NAT2 *5A	GATTTGGTCCAGG5ACCAGA6TC3P
F18141	dU propargyl FAM, NAT2 *5A	GAT5TGGTCCAGG6ACCAGATTC3P
F34324	FAM cap prop dU, NAT2 *5A	GAATC5GGTACC6GGACCAA3P
F34325	FAM cap prop dU, NAT2 *5A	GAATC5GGTACT6GGACCAA3P
2D63A	dU C6 FAM, CYP2D6 *3	CCCAGG5CATCCTG6GCTCAG3P
2D64A	dU C6 FAM, CYP2D6 *4	GGGGCGTCC5GGGGG6GG3P

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5 **Table 3.** SNPs within *N-acetyltransferase* (NAT2) and Cytochrome P450 encoding (*CYP2D6*, *CYP2C9* and (*CYP2C19*) genes were used to aid the design of HyBeacon assays. The types of polymorphism, the allele names and the sequences of F HyBeacon probes used in SNP discrimination assays are included. Bold and underlined characters in HyBeacon sequences represent the polymorphic nucleotide and the fluorophore labelled uracil respectively (F = FAM dU, E = TET dU and H = HEX dU). 3P and 3O represent 3' phosphate and 3' octanediol respectively.

Gene	Polymorphism	Allele	HyBeacon	Sequence (5' → 3')
NAT2	C ₄₈₁ → T	*4 (F1)	2303002	GAGAGGAATC <u>F</u> GGTACCTGGACC3P
		*5A (S1k)	NAT2*5	GAGAGGAATC <u>F</u> GGTACTTGGACC3P
NAT2	A ₈₀₃ → G	*4 (F1)	DdeFL1*4	GAAGTGCE <u>G</u> AAAAATATATTTAAG3P
		*5C (S1d)	DdeFL1	GAAGTGCE <u>G</u> GAGAAATATATTTAAG3P
		*4 (F1)	DdeFL1*4T	GAAGTGCE <u>G</u> AAAAATATATTTAAG3O
NAT2	G ₅₉₀ → A	*4 (F1)	TaqFL2	CTTCAA <u>F</u> TGTTTCGAGGTTCAAG3P
NAT2	G ₈₅₇ → A	*4 (F1)	BamFL1	CCTGGTGA <u>F</u> GGATCCCTTAC3P
		*7A (S3)	BamFL1*7	CCTGGTGA <u>F</u> GAAATCCCTTAC3P
CYP2D6	Deletion A ₂₆₃₇	*1	2D63C*	CCCAGG <u>F</u> CATCCTGTGCTC3P
		*1	2D63B	CCCAGG <u>F</u> CATCCTGTGCTCAG3P
		*3	2D63C	CCCAGG <u>F</u> CATCCGTGCTC3P
CYP2D6	G ₁₉₃₄ → A	*1	2D64C*	GGGCG <u>F</u> CCTGGGGGTG3P
		*1	2D64B	GGGCG <u>F</u> CCTGGGGGTGGG3P
		*4	2D64C	GGGCGTCT <u>F</u> GGGGGTG3P
		*1	2D64E	GGGCGH <u>C</u> CCTGGGGGTG3O
CYP2C9	C ₄₃₀ → T	*1	C9*2C	CATTGAGGACCG <u>F</u> EGTTCAAG3P
		*2	C9*2T	CATTGAGGACTG <u>E</u> EGTTCAAG3P
CYP2C9	A ₁₀₇₅ → C	*1	C9*3A	GAAGG <u>F</u> CAATGTATCTCTGG3P
		*3	C9*3C	GAAGG <u>F</u> CAAGGTATCTCTGG3P
CYP2C19	G ₆₈₁ → A	*1	C19m1G	GATTATTE <u>F</u> CCCGGGAACCC3P
		*2	C19m1A	GATTATTE <u>F</u> CCCAGGAACCC3P
CYP2C19	G ₆₃₆ → A	*1	C19m2G	TACCE <u>G</u> GATCCAGGGGGTG3P
		*3	C19m1A	TACCE <u>G</u> GATTACAGGGGGTG3P

Tabl 4. Oligonucleotide primers used to amplify polymorphic target sequence

Polymorphism	Primer	Sequence
NAT2*5A	195991	5'(CTGCTCTCTCCTGATTGGTCC)3'
NAT2*5A	195993	5'(CCTCTAGAATTAATTTCTGGG)3'
NAT2*5C	DdeF2	5'(CCTATAGAAAATTCAATTATAAAG)3'
NAT2*5C	DdeR	5'(CACGAGATTTCTCCCAAGG)3'
NAT2*6	TaqF2	5'(CCTGCCAAAGAAGAAACACC)3'
NAT2*6	TaqR2	5'(GTATTCATAGACTCAAAATCTTC)3'
NAT2*7A	BamF2	5'(GAAGAGGTTGAAGAAGTGCTG)3'
NAT2*7A	BamR	5'(CAAGGGTTTATTTGTTCCCTTATTC)3'
CYP2D6*3	2D63F	5'(CCACCGTGGCAGCCACTCTC)3'
CYP2D6*3	2D63R	5'(CCAGCTGGATGAGCTGCTAAC)3'
CYP2D6*4	2D64F2	5'(CGAAGCGGCGCCCGCAGG)3'
CYP2D6*4	2D64R2	5'(GGGACGGGGAAGGCGACC)3'

(iii) *Heterogeneous melting analysis of SNPs.*

- 5 PCR volumes were typically 30µl, containing approximately 200ng of DNA template, 1x PCR buffer (Pharmacia), 0.5µM each primer, 1 unit *Taq* polymerase (Amersham Pharmacia Biotech) and 1mM dNTPs (Amersham Pharmacia Biotech). Following a denaturation reaction step (94°C 5 min), PCR targets were amplified using 40 cycles comprising
- 10 denaturation (94°C 30 s), primer annealing (50°C 1 min) and extension of products (72°C 1 min). Following amplification, PCR products were precipitated with 0.1 volumes of 3M sodium acetate and 2 volumes of ethanol. After 10 minutes incubation at -20°C, 30 minutes centrifugation at 13,000 r.p.m. and two wash steps with 70% ethanol, pellets were
- 15 resuspended in 1 x hybridisation buffer / probe mix (50mM Tris pH7.4, 3mM MgCl₂, appropriate HyBeacon), where 5µl of buffer/probe mix was added per initial PCR reaction. F-Q HyBeacons were typically used at concentrations between 500nM-1µM, whilst F HyBeacons were used between 100nM and 300nM concentrations. 5µl reaction volumes were
- 20 analysed with a LightCycler™ (Roche) using a melting curve analysis

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program. Hybridisation analysis comprised an initial fluorescence read (30°C for 30 s), hybridisation (94°C for 1 min followed by 30°C for 2 min), normalisation (65°C for 1 s, 85°C for 1 s, 30°C 1 s) and melt analysis (30°C to 95°C, with a 0.1°C/s transition rate). With the exception of
5 normalisation, which used single fluorescence acquisitions, fluorescence was monitored continuously. Melting curves were constructed using the LightCycler software, by plotting the negative derivative of fluorescence with respect to temperature ($-dF/dT$ on the y-axis) against temperature (x-axis).

10

(iv) *Homogeneous 'real-time' PCR amplification assays.*

PCR volumes were 20µl, containing 2µl of 50% saliva or approximately 200ng genomic DNA, 1x Z-Taq™ buffer (TaKaRa) or 1x HyBeacon PCR buffer (10mM Tris.Cl pH 8.8, 25mM KCl, 3.5mM MgCl₂,
15 5ng/µl BSA), 0.5µM primers, 1 unit Taq polymerase (Amersham Pharmacia Biotech) and 1mM dNTPs. 'Real-time' PCR assays, that utilised fluorescent probes to monitor the accumulation of amplified target, also contained an additional 500-1000nM or 100-300nM of the appropriate F-Q and F HyBeacon/s respectively. Polymorphic target sequences were
20 amplified with LightCycler™ (Roche) and ABI PRISM® 7700 Sequence Detector (Applied Biosystems) instruments. Reactions, performed in LightCycler capillaries, were denatured by incubation at 95°C for 1 min (genomic and plasmid DNA) or 5-10 min (saliva samples), prior to amplification of polymorphic targets using 40-50 cycles, comprising
25 denaturation (95°C 0 s), primer annealing (Faq 10 s) and extension of products (72°C 10 s). Fluorescence acquisition was performed at the end of each primer annealing step. The fluorescence acquisition temperature (Faq) varies between amplicons and HyBeacons, where Faq is approximately midway between matched and mismatched probe T_{ms} (see
30 table 5). For example, 2D64C* HyBeacon assays employ a 57°C Faq to discriminate CYP2D6 *1 and *4 SNPs by real-time amplification. Following

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amplification, reactions were denatured (95°C 0 s) and cooled (35°C 2 min) prior to melt analysis (35°C to 95°C, with a 0.1°C/s transition rate), where fluorescence was acquired continuously. Melt peaks were constructed using LightCycler software, by plotting the negative derivative of
5 fluorescence with respect to temperature ($-dF/dT$ on the y-axis) against temperature (x-axis).

(v) *Asymmetric amplification of HyBeacon targets.*

Asymmetric PCR was used to generate single-stranded DNA
10 target molecules for probe hybridisation. Amplifications were performed in LightCycler capillaries. Anti-sense primers were employed to amplify the single-stranded product containing the homologous DNA sequence required for HyBeacon hybridisation. Sense primers were involved with the initial amplification of double-stranded DNA to generate the strand that did
15 not contain the probe-binding site. Anti-sense and sense primers were typically used at a ratio of 50:1. pGEM-T plasmids containing polymorphic NAT2 and CYP2D6 targets were used as PCR templates. PCR reaction volumes were typically 20µl, containing approximately 200ng of plasmid DNA, 1x Z-Taq™ PCR buffer (TaKaRa), 0.5µM anti-sense primer, 10nM
20 sense primer, 1 unit Taq polymerase (Amersham Pharmacia Biotech), 1mM dNTPs (Amersham Pharmacia Biotech) and the appropriate hybridisation beacon. Homogeneous amplification and melting peak analysis was performed as described above.

25 (vi) *Solid phase analysis of polymorphic targets.*

PCR amplification was performed as described above for the heterogeneous assays, with the exception that the anti-sense primer was biotinylated at the 5' terminus. Following amplification, 10-15µl of biotinylated PCR product was added to individual wells of streptavidin
30 coated microtitre plates (Hybaid). 1x DASH buffer gold (Hybaid) was added to each well to yield a final volume of 50µl. Following a 1-hour

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incubation at room temperature, the solution was removed from each well. 50µl 0.1M NaOH was added to wells to denature double-stranded DNA. After 5 minutes incubation, wells were washed once with 50µl 0.1M NaOH and twice with 50µl 1x DASH buffer to remove the non-biotinylated DNA strand. An excess of HyBeacon (>1µM) in 1x DASH buffer (2µl probe + 48µl buffer) was added to each well. Probes were hybridised to immobilised single-stranded DNA by heating reactions to 95°C for 1 minute then cooling to 25°C at an approximate rate of 0.08°C/sec. Solution and unhybridised probe was removed from wells and replaced with 50µl of fresh 1x DASH buffer. Melting analysis of hybridised probe was performed on a DASH (Dynamic Allele Specific Hybridisation) instrument (Hybaid) using temperature transition rates between 0.02-0.07°C/sec.

(vii) *Multiplex HyBeacon target detection*

Reactions containing multiple primer pairs and HyBeacon probes were performed using the ABI PRISM® 7700 Sequence Detector. NAT2*4 (*7A locus), NAT2*4 (*5C locus) and CYP2D6*1 polymorphic targets were amplified and detected using FAM, TET and HEX labelled HyBeacon probes respectively (table 4). Following a denaturation reaction step (95°C 5 min), polymorphic targets were amplified from genomic DNA using 40 cycles, comprising denaturation (95°C 15 s), primer annealing (50°C 30 s) and extension of products (72°C 30 s). Fluorescence acquisition was performed during each primer annealing step of amplification.

Results and Discussion

(i) *The polymorphic target sequences.*

The human *N-acetyltransferase 2* (NAT2) locus has been demonstrated to be polymorphic. Defective copies of the NAT2 gene are known to result in slow acetylation of several arylamine drugs and toxicants. Epidemiological studies have associated this slow acetylation

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phenotype with a risk for bladder and colorectal cancers. Analysis of polymorphic *NAT2* loci has identified a number of slow alleles, containing nucleotide substitutions (see Table 1). These substitutions include point mutations at positions 481 (C to T), 590 (G to A), 803 (A to G) and 857 (G to A), which produce *5A, *6, *5C and *7A restriction fragment length polymorphisms (RFLPs) respectively. At each of these polymorphic loci, *1 is the allelic variant which occurs more frequently in human genomes.

The Cytochrome P450 enzyme (debrisoquine 4-hydroxylase), encoded by the genes such as *CYP2D6*, *CYP2C9* and *CYP2C19* in humans, is responsible for the metabolism of more than 30 commonly prescribed drugs, including anti-depressants, anti-arrhythmics and anti-hypertensive agents. Approximately 5-10% of caucasians exhibit a poor metabolism phenotype due to deficient activity of the cytochrome P450 enzyme. Many allelic variants have been identified in the *CYP2D6* gene locus, the most common of which being the *CYP2D6**3 (also known as *CYP2D6A*) and *CYP2D6**4 (also known as *CYP2D6B*) single nucleotide polymorphisms. Individuals possessing *3 and *4 genotypes have been shown to possess poor enzyme activity phenotypes.

The *NAT2* and *CYP* polymorphisms have been used to test the potential of hybridisation beacons to detect specifically amplified DNA sequences and to discriminate targets containing single nucleotide polymorphisms.

(ii) Differential probe hybridisation to oligonucleotide targets.

When a HyBeacon probe hybridises to a target sequence, the interaction may be either perfectly matched or mismatched. Figure 1 illustrates the differences between matched, mismatched and double mismatched duplexes, classifying each type of interaction. HyBeacon probes were hybridised to perfectly matched and mismatched oligonucleotides and analysed in a LightCycler. When the quantities of fluorescence emitted from HyBeacons in single-stranded and double-

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stranded states were compared, it was observed that significantly more fluorescence was emitted when probes were hybridised to target molecules than when free in solution. These differences in fluorescence emission, generated by single-stranded and double-stranded HyBeacon probes, were statistically significant ($p < 0.01$ in single-factor ANOVA) and provided a method by which the presence of target DNA could be detected through fluorescence quantitation (figure 2).

Monitoring the changes in fluorescence emission caused by alterations in temperature and probe hybridisation status allows the generation of melting peaks with HyBeacon/homologue pairs. HyBeacon probes hybridised to mismatched oligonucleotides produce melt curves with reduced T_m s compared with probes hybridised to fully complementary target molecules. Figure 2 demonstrates the differential hybridisation of a NAT2 *4 HyBeacon (at the *5A SNP) to matched and mismatched oligonucleotide targets. Regions of mismatch reduce probe T_m and allow discrimination of polymorphic targets through melt peak analysis. Matched, single mismatched and multiple mismatched targets may be reliably discriminated by melt peak T_m . Furthermore, fluorescence acquisition performed at a temperature midway between matched and mismatched T_m s allows discrimination of polymorphic targets on the basis of fluorescence quantitation. At the fluorescence acquisition temperature, the matched HyBeacon is hybridised to its target and is emitting more fluorescence than a mismatched probe that has melted away from its target (figure 2).

In solution, HyBeacons only emit small amounts of background fluorescence. However, upon binding to target sequences, significantly more fluorescence is emitted as a direct result of hybridisation. It has been demonstrated that sequences differing by as little as a single nucleotide may be distinguished by (i) the amount of fluorescence produced when the hybridisation beacon molecule hybridises to its target sequence and (ii) the melting temperature (T_m) of the probe/target duplex.

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Fluorescence quantitation and melting analysis methods have been performed with F-Q and F HyBeacon probes, generating results of comparable quality. Figure 3 illustrates melting curves derived from F and F-Q NAT2 *4 HyBeacons hybridised to oligonucleotide targets. F-Q
5 HyBeacons may have some dependence on fluorophore and quencher spacing and angular disposition effects (data not shown). However, F HyBeacons display elevated levels of fluorescence emission upon target hybridisation despite the absence of a quencher moiety. Fluorophore moieties in F and F-Q HyBeacon probes emit significantly more
10 fluorescence when in the double-stranded state than in the single-stranded conformation (see below).

(iii) Varieties of single nucleotide polymorphisms.

Discrimination of the single base substitution polymorphisms present in the NAT2 and CYP2D6 alleles has been demonstrated using
15 HyBeacon probes. A series of oligonucleotide targets were hybridised to the TB0993 NAT2 *4 probe to test the ability of hybridisation beacon molecules to discriminate insertion and deletion (InDel) polymorphisms. Three insertion and three deletion oligonucleotides, varying in type and
20 position of polymorphism, were analysed. Each InDel target generated a significantly reduced T_m compared with HyBeacon hybridised to perfectly matched oligonucleotide (figure 4). Similar to substitution polymorphisms, InDels may also be distinguished by the T_ms of HyBeacon/target duplexes and the amount of fluorescence emitted at a temperature in-between the
25 T_ms of matched and mismatched probe.

(iv) Discrimination of SNPs in PCR products (Heterogeneous assays).

Heterogeneous assays, that perform target amplification and SNP discrimination in separate tubes, were carried out with NAT2 *5A, *5C
30 and *6 polymorphisms and with CYP2D6 *3 and *4 SNPs. Successful heterogeneous assays, allowing reliable SNP discrimination through melt

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peak analysis, have been developed for all polymorphisms tested. PCR products containing polymorphic nucleotides were amplified from *NAT2* and *CYP2D6* template DNA. Amplicon sizes ranged between 80bp and 282bp in length. PCR products were isolated and resuspended in hybridisation buffer containing HyBeacon probe. Probes were hybridised to PCR targets and melting analyses were performed in LightCycler capillaries, generating melt peaks with Tms dependent upon the identity of the PCR target. HyBeacons readily discriminate matched and mismatched PCR targets by the melting temperature of probe/target duplexes. F-Q and F HyBeacon variants both perform well in heterogeneous SNP discrimination assays.

Assays performed with the *CYP2D6**3 polymorphism demonstrate how F and F-Q HyBeacons permit SNP discrimination in heterogeneous analyses (figure 5). A 119bp PCR product was amplified from *CYP2D6**3 polymorphic DNA. PCR products were isolated and resuspended in hybridisation buffer containing either the 2D63A (F-Q) or 2D63B (F) HyBeacon probes. The 2D64 F HyBeacon was used at a 5 times lower concentration than the F-Q probe because of the larger fluorescence background caused by the lack of quencher. Figure 5 displays the melting curves derived from HyBeacon hybridisation to PCR targets containing the *1 and *3 *CYP2D6* alleles. 2D63A and 2D63B probes possess identical nucleotide sequences, being fully complementary to the *1 allele of the *CYP2D6* gene and, therefore, containing a single base mismatch when hybridised to the *3 allele. The 2D63A F-Q HyBeacon generated melt peaks with Tms of approximately 56°C and 65°C when hybridised to *3 and *1 allelic sequences respectively. The 2D63B F HyBeacon generated melt peaks with similar Tms of approximately 58°C and 65°C when hybridised to mismatched and matched PCR products respectively. The melting temperatures, generated by HyBeacon hybridisation to the two alleles of the SNP, are highly reproducible and statistically significant ($p < 0.01$ in single factor ANOVA). Therefore,

CYP2D6 *1 and *3 genotypes, correlating to normal and deficient enzyme metabolism phenotypes respectively, are reliably discriminated in heterogeneous HyBeacon assays.

5 (v) *Real-time detection of nucleic acid sequences.*

The amount of fluorescence emitted from HyBeacon probes is significantly greater when the oligonucleotides are hybridised to complementary nucleic acid sequences than when in the single-stranded conformation. Therefore, HyBeacons may be included in reactions to
10 monitor the real-time accumulation of specific DNA targets throughout the course of PCR amplification. Figure 6 demonstrates detection of *CYP2D6**1 sequence present in genomic and saliva DNA, using the 2D64C* HyBeacon to monitor the accumulation of product with each cycle of amplification.

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(vi) *'Real-time' discrimination of SNPs (Homogeneous assays).*

When HyBeacon probes hybridise to polymorphic target sequences, interactions may either be perfectly matched or mismatched. Positions of nucleotide mismatch destabilise probe/target duplexes such the T_m of
20 hybridisation is reduced compared with fully complementary sequences. Since the amount of fluorescence emitted from hybridised HyBeacon is significantly greater than single-stranded probe, polymorphic target sequences may be discriminated on the basis of hybridisation T_m . The annealing (and fluorescence acquisition) temperature of PCR may be
25 optimised to accomplish real-time discrimination of closely related DNA sequences, by selective probe hybridisation, such that only target sequences that are fully complementary to HyBeacon probes instigate increased in fluorescent signals during amplification. Polymorphic sequences containing SNPs may be identified using the fluorescence data
30 derived during real-time amplification. For example, if a HyBeacon probe is designed to be fully complementary to a DNA sequence containing a

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mutation, increases in fluorescence emission are only generated in the presence of the mutant allele.

HyBeacon probes were incorporated into polymerase chain reactions designed to amplify *NAT2* and *CYP* polymorphic sequences. At each cycle of amplification, single fluorescence readings were acquired at the primer annealing stage, at a temperature midway between the *T_m*s of matched and mismatched HyBeacon. At the fluorescence acquisition temperature, the HyBeacon is expected to be hybridised to perfectly matched target but is not expected to be hybridised to a mismatched sequence. Differential probe hybridisation, at the fluorescence acquisition temperature, causes reactions containing perfectly matched template to result in fluorescence increases during amplification, whilst reactions containing mismatched template do not yield fluorescence increases. Homogeneous SNP analysis is demonstrated here using the F HyBeacon 0203002, which was employed to discriminate *NAT2* *4 and *5A polymorphisms. The HyBeacon is perfectly matched to *4 allele of *NAT2* and has a single base mismatch when hybridised to *5A sequence. Figure 7a demonstrates 'real-time' discrimination of SNPs, where only reactions containing the *4 allele generate significant increases in fluorescence emission during PCR cycling. Reactions containing only mismatched *5A alleles do not produce increases in fluorescence emission during amplification.

Figure 8 is another example of real-time HyBeacon analysis that demonstrates detection and discrimination of polymorphic *CYP2D6* *1 and *4 sequences, using plasmid DNAs as the source of template. Discrimination of polymorphic sequences present in genomic DNA and saliva samples may also be achieved by real-time HyBeacon PCR analysis. The 2D64C* HyBeacon, presented in figure 8, is perfectly matched to the *1 allele of the *CYP2D6* gene and, as such, specifically detects the amplification of the *1 sequence through real-time increases in fluorescence emission. Reactions containing only *CYP2D6**1 sequences

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generate relatively large emission increases whilst samples containing only *4 alleles do not display significant fluorescence increases. Reactions that contain both *1 and *4 alleles display intermediate increases in the quantity of fluorescence emission. Use of the 2D64C HyBeacon, which is fully complementary to the CYP2D6*4 allele, permits confirmation of 2D64C*
5 genotyping results (unpublished data). As with TaqMan™ probes, molecular beacons, hybridisation probes and Scorpion primers, two HyBeacon probes are required to genotype samples, with respect to biallelic SNPs, by real-time PCR to ensure accurate identification of
10 homozygous and heterozygous DNA.

(vii) Discrimination of SNPs by melting curve analysis

Polymorphic DNA sequences may also be detected and discriminated in an 'end-point' format using HyBeacon probes through melt curve analysis and
15 T_m determination. Homogeneous melting curve analysis of HyBeacon/target duplexes may be performed on LightCycler reactions immediately following amplification. The melting temperatures derived from melt curve analysis permits identification of target DNA sequences, where T_ms derived from fully complementary HyBeacons are significantly greater
20 than mismatched probe interactions. Melting analysis performed post-amplification with the 0203002 HyBeacon and the *4 and *5A polymorphic targets generated melt peaks possessing T_ms of approximately 62°C and 54°C with matched and mismatched sequences respectively (figure 7b). Melt peak T_ms, produced by hybridisation with matched and mismatched
25 target sequences, are highly reproducible for a given SNP and significantly different between SNPs. Therefore, reliable discrimination of SNPs is achieved by analysis of HyBeacon melting temperatures. Post-amplification melting analysis permits validation of 'real-time' fluorescence data, confirming that the presence or absence of fluorescence increases in
30 PCR are actually correlated with the presence of matched or mismatched targets respectively. Therefore, post-amplification melts permit

differentiation between reactions that do not produce fluorescence increases because of the presence of mismatched target and those reactions that do not generate fluorescence increases due to the total absence of target or a failure of PCR amplification. Both F-Q and F HyBeacon variants have been demonstrated to perform well in 'real-time' amplification assays and to generate post-amplification melting curves in homogeneous assays. However, F HyBeacons have been found to typically produce superior quality post-amplification melts compared with F-Q probes of identical DNA sequences.

10 With F HyBeacon probes, homozygous samples generate single melt peaks, which are matched or mismatched depending on the identity of the target sequence, whilst heterozygous DNA produce melting traces that possess both matched and mismatched peaks. Figure 9 demonstrates detection and discrimination of polymorphic *CYP2D6* *1 and *4 sequences, amplified from genomic DNA samples, by melt peak analysis. The 2D64C* HyBeacon generates a single melt peak possessing a T_m of approximately 60°C when hybridised to homozygous DNA containing fully complementary *1 alleles. Mismatched probe hybridisation to homozygous *4 samples results in a single melt peak with a T_m of approximately 49°C.

15 20 Heterozygous samples, containing both *1 and *4 alleles, generate traces possessing both 60°C and 49°C melt peaks.

(viii) *Identification of homozygous and heterozygous samples.*

It is considered important that a technology for scoring SNPs is capable of identifying whether a sample is homozygous or heterozygous for a particular allele. Heterozygote analysis utilising F-Q HyBeacons has been found to require two distinct probes, perfectly matched to the two alleles of an SNP, for the identification of heterozygous samples. Two HyBeacons are thought to be necessary since F-Q probes have been found to typically generate only matched melting peaks in reactions containing a mixture of fully complementary and mismatched targets. The

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mismatched melt peaks are not observed in heterozygous reactions, where either binding to fully complementary target is either thermodynamically favoured or melting analysis reveals the matched curve whilst masking the mismatched peak. If the two HyBeacons possessed spectrally distinct fluorophores that could be excited and detected simultaneously, homogeneous heterozygote discrimination assays using F-Q probes could be performed in a single tube. However, at present the LightCycler may only excite fluorescein. Therefore, differential beacon hybridisation analysis using two distinct HyBeacons in the same LightCycler capillary was performed using probes possessing significantly different Tms. Two F-Q HyBeacon probes, F17834 and F17835, of different length and Tm were used in isolation and in combination to discriminate homozygous and heterozygous NAT2 *4 and *5A samples (figure 10). The F17834 and F17835 probes generate matched melting curves possessing Tms of approximately 60°C and 52°C when hybridised to homozygous *4 and *5A DNA respectively. When the F17834 and F17835 HyBeacons are used in combination with a mixed DNA, containing *4 and *5A sequences (heterozygote), two melt peaks possessing Tms of approximately 59°C and 52°C are generated in the same melting trace. The presence of two peaks within a single melting trace may be employed as an indicator of heterozygosity.

An important feature of the F HyBeacon technology is that, unlike F-Q probes and previously reported fluorescent probes, homozygous and heterozygous samples may be reliably identified using a single F HyBeacon. Fluorescent probes, such as TaqMan™ probes, molecular beacons and Scorpion primers, typically require two probes to reliably detect and discriminate biallelic sequences by real-time PCR methods. Furthermore, hybridisation probes require a pair of fluorescent oligonucleotides to identify homozygous and heterozygous DNA by melting curve analysis. HyBeacon probes may reliably distinguish homozygous and heterozygous samples through melting curve analysis by Tm

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determination and the number of melt peaks generated. Figures 9 and 11 demonstrate identification of homozygous and heterozygous samples by melt peak analysis, where homozygous samples are identified by specific Tms and heterozygotes by the presence of two peaks with a single melting trace. Figure 11 illustrates the melting curves derived from a NAT2 *5C F HyBeacon (DdeFL1) hybridised to homozygous and heterozygous DNA targets. In homogeneous and heterogeneous assays, DdeFL1 generates single melting peaks with Tms of approximately 54°C and 47°C with homozygous matched (*5C) and mismatched (*4) targets respectively.

10 Samples heterozygous for the *4 and *5C alleles were found to generate both the matched and mismatched peaks within a single melting trace. Therefore, the presence of two peaks within a HyBeacon melting trace permits reliable identification of heterozygous samples.

The ability to detect heterozygous DNA using HyBeacon probes depends on the magnitude of the ΔT_m (the difference in T_m between fully complementary and mismatched hybridisation). Table 5 illustrates the T_m and ΔT_m values displayed by HyBeacon probes during hybridisation to NAT2 and CYP polymorphic genes. A probe that permits reliable identification of homozygous and heterozygous samples by melt peak analysis has been developed for each of the nine SNPs investigated here.

20 It is apparent that ΔT_m values exceeding approximately 5.2°C are required to reliably detect the presence of heterozygous DNA by melting curve analysis. The ΔT_m of hybridisation depends on the length of the probe, the position of the nucleotide mismatch and the identity of the mismatch. The length of HyBeacon oligonucleotides should be sufficient enough to ensure specificity of hybridisation, but should not be excessive causing insensitivity to mismatch. HyBeacons should be designed such that polymorphic nucleotides are located towards the centre of probes since mismatches at central positions have greater effects on T_m than mismatches located at

25 oligonucleotide termini. All nucleotide mismatches exhibit destabilising effects on hybridisation T_m , but the magnitude of destabilisation depends

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on the type of mismatch interaction. Mismatched interactions involving G (i.e. G/T, G/A and G/G) are the most stable at room temperature and mismatches containing C (i.e. C/T, C/A and C/C) are the least stable. Therefore, to maximise the affect of mismatch on ΔT_m , mismatches involving G are avoided and mismatches containing C are pursued.

Table 5. The T_m and ΔT_m values derived from HyBeacon hybridisation to NAT2 and CYP sequences, including the matched and mismatched nucleotide interactions occurring at the polymorphic position. T_m values were obtained from several independent analyses to account for experimental variation and the mean and standard error values are included. Values in italics were derived from hybridisation to oligonucleotides. The ability to identify heterozygous DNA is dependent on the ΔT_m and is identified by the presence of both matched and mismatched melt peaks in a single melting trace.

HyBeacon	Nucleotide interactions	Matched T_m (mean \pm SE)	Mismatched T_m (mean \pm SE)	ΔT_m	Identification of heterozygous DNA?
2303002	C/G, C/A	63.1°C \pm 0.1	55.2°C \pm 0.1	7.9	Yes
NAT2*5	T/A, T/G	61.3°C \pm 0.2	57.1°C \pm 0.2	4.2	No
DdeFL1*4	A/T, A/C	53.2°C \pm 0.2	42.4°C \pm 0.1	10.8	Yes
DdeFL1	G/A, G/T	54.1°C \pm 0.1	47.6°C \pm 0.1	6.5	Yes
BamFL1	G/C, G/T	57.6°C \pm 0.6	(52.4°C)	(5.2)	(No)
BamFL1*7	A/T, A/C	(56.7°C)	48.9°C \pm 0.4	(7.8)	(Yes)
2D63C*	T/A, T/Del	59.2°C \pm 0.1	53.2°C \pm 0.1	6.0	Yes
2D63C	G/C, G/Ins	59.3°C \pm 0.1	52.8°C \pm 0.1	6.5	Yes
2D64C*	C/G, C/A	60.4°C \pm 0.1	49.3°C \pm 0.1	11.1	Yes
2D64C	T/A, T/G	56.8°C \pm 0.6	53.2°C \pm 0.4	3.6	No
C9*2C	C/G, C/A	57.8°C \pm 0.1	48.2°C \pm 0.2	9.6	Yes
C9*2T	T/A, T/G	54.8°C \pm 0.1	52.1°C \pm 0.1	2.7	No
C9*3A	T/A, T/C	54.5°C \pm 0.1	45.5°C \pm 0.2	9.0	Yes
C9*3C	G/C, G/A	56.3°C \pm 0.2	50.9°C \pm 0.1	5.4	Yes
C19m1G	G/C, G/T	54.4°C \pm 0.1	48.7°C \pm 0.2	5.7	Yes
C19m1A	A/T, A/C	52.9°C \pm 0.3	45.0°C \pm 0.1	7.9	Yes
C19m2G	C/G, C/A	57.5°C \pm 0.2	47.0°C \pm 0.2	10.5	Yes
C19m2A	T/A, T/G	(56.6°C)	51.5°C \pm 0.3	5.1	(No)

(ix) Multiplex analysis of SNPs.

The potential for multiplex analysis using HyBeacon probes has been examined using mixtures of specific and non-specific PCR targets. HyBeacons hybridise to specific DNA targets amplified throughout PCR, resulting in increases in fluorescence emission. Increases in HyBeacon fluorescence emission do not occur with non-specific DNA targets that lack the probe's target sequence. Different proportions of specific and non-specific PCR templates (100, 80, 60, 40, 20, 10 and 5% specific sequence in non-specific DNA) were analysed in homogeneous assays to test the ability of the 2D64B HyBeacon probe to detect the amplification of specific target. In reactions that amplified only the specific target, i.e. no non-specific amplification, all starting concentrations of specific target were readily detected, with equivalent increases in fluorescence emission (figure 12a). However, when both specific and non-specific targets were amplified in the same reaction, the ability of the probe to detect specific amplification decreased as the proportion of specific PCR template was reduced (figure 12b). The results derived from this experiment suggest that HyBeacon multiplex assays containing up to four or five distinct targets may be possible. However, the use of increased signal fluorophores and higher sensitivity detection instruments may allow multiplex analysis to be extended past five targets.

Functionality of HyBeacon probes has been demonstrated to date using FAM, HEX and TET fluorescent dyes, where each hybridised probe emits significantly greater amounts of fluorescence than single-stranded HyBeacons. Multiple polymorphic sequences may be simultaneously amplified; detected and discriminated with these spectrally distinct HyBeacons using real-time PCR and melting peak analyses. Fig. 13a demonstrates simultaneous amplification and specific detection of *NAT2*4* and *CYP2D6*1* alleles, in a single ABI PRISM 7700 microtitre plate well, using FAM and HEX labelled HyBeacon probes respectively. The identity of polymorphic sequences may also be determined using FAM, HEX and

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TET probes by melting temperature determination. An Excel macro was created to convert the melt curve data obtained from the ABI PRISM 7700 to melt peaks. Fig. 13b displays the peaks obtained from 2D64C*, 2D64E and DdeFL1*4T probes labelled with FAM, HEX and TET dyes respectively. Melt peaks have been obtained from HyBeacon hybridisation to complementary oligonucleotides and PCR amplified targets.

(x) Optimisation of HyBeacon assays.

Various HyBeacon assay parameters may be modified to potentially improve the efficiency of target detection and SNP discrimination. Examples of reaction conditions that have been analysed for assay optimisation are presented here:

a) Buffer optimisation: Following a small amount of buffer optimisation, heterogeneous melting analysis experiments were performed in 1.25mM Tris.Cl pH8.0, 250nM MgCl₂, 25nM DTT. This hybridisation buffer was demonstrated to generate high quality melting curves with the majority of HyBeacons synthesised to date. However, the F17836 probe did not generate melting curves in this buffer even when hybridised to oligonucleotide targets. Subsequently, a study of MgCl₂ concentration versus HyBeacon melting temperature was performed. It was demonstrated that whilst no melt peaks were obtained with F17836 in the above buffer, very good quality melting curves were obtained in 50mM Tris, 3mM MgCl₂. Furthermore, it was demonstrated that there is a very strong correlation between MgCl₂ concentration and melt peak T_m. This relationship was studied for the F17831, TB0993, F17834, F17835 and B9414 HyBeacons, where R² values of 98.9%, 97.9%, 99.4%, 99.3% and 98.8% were generated respectively in regression analyses performed between 0.1mM and 10mM concentrations (see figure 14). More than a 10°C shift in HyBeacon T_m may be achieved by altering MgCl₂ concentration. It may be possible to design differential beacon

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hybridisation assays where specific HyBeacon Tms are selected on the basis of buffer composition.

Amongst the commercially available PCR buffers tested in homogeneous amplification assays, TaKaRa buffer was found to be superior. Pharmacia, *Taq* Gold and TaKaRa PCR buffers and the corresponding *Taq*, *Taq* Gold and Z-*Taq* polymerases were compared for their effectiveness in HyBeacon assays. Assays performed with *Taq* Gold buffer and polymerase did not function at all, such that no real-time amplification curves or melt peaks were generated. Pharmacia and TaKaRa buffers both generate amplification curves and melt peaks with *Taq* and Z-*Taq* polymerases. However, TaKaRa buffer typically produces superior results even when additional MgCl_2 is included in the Pharmacia buffer. When amplification and detection efficiencies using Pharmacia PCR buffer were analysed in a series of MgCl_2 concentrations, the optimal concentration was found to be between 3.0mM and 3.5mM. TaKaRa buffer is known to contain 3.0mM MgCl_2 , but the other constituents are unknown.

Stratagene's Optiprime kit was employed to obtain an indication of which components and conditions are required for the optimisation of HyBeacon PCR assays. The Optiprime kit consists of 12 individual buffers of various pHs (8.3, 8.8 and 9.2), containing different concentrations of MgCl_2 (1.5mM and 3.5mM) and KCl (25mM and 75mM). The efficiency of target amplification and detection was not noticeably affected by pH, but was significantly affected by MgCl_2 and KCl concentration, where 3.5mM and 25mM were optimal respectively (in 1x buffer). Using the information obtained from the Optiprime kit, a 10x HyBeacon PCR buffer (100mM Tris.HCl pH8.8, 250mM KCl, 35mM MgCl_2) was constructed. This buffer was found to function relatively well in HyBeacon assays, generating high quality melting peaks in post-amplification analysis. However, the magnitude of the fluorescence increases resulting from real-time analysis was reduced compared with analyses performed in TaKaRa PCR buffer. Therefore, a series of PCR adjuncts were added to the HyBeacon PCR

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buffer in an attempt to improve the real-time target detection efficiency. Of the putative enhancers of PCR that were examined in the HyBeacon PCR buffer, only BSA was found to have a profound positive affect on the efficiency of real-time amplification. Working concentrations of BSA were studied between 0µg/µl and 1µg/µl. Increasing the concentration of BSA from 0µg/µl to 100ng/µl significantly enhanced the efficiency of real-time target detection. However, as a result of the increased BSA concentrations, the quality of post-amplification melting peaks was reduced. Therefore, an optimal BSA concentration was sought that permitted enhanced real-time amplification but did not decrease melt peak quality significantly. This optimal working concentration was found to be between 2.5ng/µl and 5ng/µl (see figure 15) and, therefore, 50ng/µl of BSA was included in the 10x HyBeacon PCR buffer. This buffer has been demonstrated to function with a comparable efficiency to TaKaRa PCR buffer.

b) Choice of amplicon: With the exception of two probes F18140 and F18141, all of the HyBeacons tested generate very high quality melting curves with oligonucleotide homologues. However, not all of these probes produce high quality melts with large PCR targets. Alterations in amplicon size and primer position relative to the polymorphic site allow more efficient probe hybridisation and the generation of superior melting curves. Significant variations in 'real-time' amplification detection and melt peak discrimination efficiency have been observed for one of the NAT2 *6 probes when using two amplicons differing by only 22bp (figure 16).

c) Probe melting temperature: The T_m of a hybridisation beacon may affect the quality of post-amplification melting curves. Many of the early HyBeacons that were synthesised and tested were found to produce a background fluorescence effect at approximately 60-65°C. Numerous HyBeacons possessing matched T_m s greater than approximately 58°C

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wer found to have their matched melt peak obscured by this background fluorescence effect, whilst the mismatched peaks with lower Tms were clearly visible in the melting trace. Probes possessing matched Tms of less than 58°C may perform more efficiently in post-amplification melting analysis experiments. F-Q and F HyBeacon probes were designed for the CYP2D6 *3 and *4 polymorphisms. The original CYP2D6 F HyBeacons possessed a number of advantages over the F-Q probes and generated high quality real-time PCR amplification data that permitted reliable discrimination of *3 and *4 SNPs. However, these F HyBeacon probes (2D63B and 2D64B) did not generate high quality melting peaks due to a significant overlap with a background fluorescence effect. Therefore, SNPs and homozygous and heterozygous samples could not be identified by melt analysis with these high Tm probes. The *3 and *4 HyBeacons were redesigned to be 2 (2D63C) and 3 (2D64C) nucleotides shorter respectively, such that the Tms were significantly reduced. Both of these reduced Tm probes generate high quality real-time amplification curves and post-amplification melt peaks, allowing extremely reliable SNP discrimination and heterozygote analysis. In contrast to the 2D63B and 2D64B probes, 2D63C and 2D64C generate both matched and mismatched melt peaks during post-amplification analysis, displaying little or no overlap with the background fluorescence effect.

d) HyBeacon concentration: The amount of HyBeacon included in an assay has been found to affect the quality of results generated, through variations in signal:background fluorescence ratios. If excess probe is included in an assay, the background fluorescence masks the hybridisation-mediated alterations in fluorescence. Superior quality melting curves have been observed in many instances when using reduced concentrations of HyBeacon. The optimal concentration of F HyBeacon probe, which permits the generation of high quality real-time amplification data and post-amplification melt peaks, is typically between 100 and 300nM. Reduced

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HyBeacon concentrations appear to eliminate the background fluorescence affect described above.

e) *Asymmetric PCR*: All HyBeacon assays described hitherto have
5 employed symmetric PCR protocols to amplify double-stranded DNA
targets. Probes hybridising to double-stranded DNAs must compete with
the target's homologous strand, such that this competitive binding may
reduce HyBeacon hybridisation efficiency. Asymmetric PCR is a technique
that is employed to generate single-stranded PCR products. HyBeacons
10 may hybridise to single-stranded targets with higher efficiency than to
double-stranded molecules due to the absence of the competing DNA
strand. Asymmetric PCR was applied to eight HyBeacon SNP assays, to
examine whether the technique is superior to symmetric amplification.
Four of the eight HyBeacon assays possessed equivalent detection
15 efficiencies in symmetric and asymmetric amplifications, with similar
increases in fluorescence emission. One HyBeacon assay demonstrated a
reduced efficiency in asymmetric assays compared with symmetric
amplifications (figure 17a), whilst three other assays demonstrated greater
increases in fluorescence emission with asymmetric amplification than with
20 symmetric PCR (figure 17b). Furthermore, many of these HyBeacon
assays produced superior post-amplification melting curves with
asymmetrically amplified target compared with symmetric reactions (data
not shown). Therefore, in some cases it may be beneficial to adopt
asymmetric target amplification for potentially higher sensitivity SNP
25 discrimination assays. However, the mechanism that generates
asymmetric single-stranded DNAs is linear instead of logarithmic, therefore
detection of amplification and discrimination of SNPs is achieved at a
significantly higher cycle number (figure 17b) than in symmetric
amplifications. This increase in threshold cycle could extend assay
30 duration and may affect reactions containing low concentrations of genomic
DNA.

(xi) *Discrimination of SNPs on a solid phase.*

NAT2 *4 and *5A polymorphic targets were amplified from genomic DNA using a biotinylated primer of the same sequence as 195993' or 195991. Biotinylated PCR products were immobilised on 96 well streptavidin coated microtitre plates. DNA targets were denatured with NaOH and the non-biotinylated PCR strand was removed, leaving a single-stranded DNA target bound to the surface of the well. HyBeacon probes, typically F17832 and 0203002, were hybridised to the immobilised single-stranded targets. After hybridisation, excess probe was removed and melting analysis was performed using a DASH (Dynamic Allele Specific Hybridisation – Hybaid) instrument. HyBeacon melting curves were obtained from matched and mismatched immobilised targets, allowing reliable discrimination of SNPs (figure 18). The F17832 HyBeacon produced melting curves of poor quality in heterogeneous LightCycler assays. However, good quality melt analysis and reliable SNP discrimination was achieved with this probe in the DASH instrument. LightCycler and DASH melting analyses utilise double-stranded and single-stranded targets respectively. Significantly superior quality melting curves are obtained from single-stranded targets because of the lack of PCR homologue competing with the HyBeacon for target hybridisation. The successful use of the HyBeacons in both homogeneous and solid phase formats provides a versatile system in which large numbers of assays can be performed, potentially in some form of array system.

25

(xii) *The 5'-3'-exonuclease activity of Taq polymerase.*

To ensure that HyBeacon assays are distinct from the TaqMan system, two DNA polymerases, Deep Vent (New England Biolabs) and Stoffel fragment (Pharmacia), that lack 5'-3'-exonuclease activity were tested in 'real-time' amplification assays. 5'-3'-exonuclease activity is essential in TaqMan assays, where Taq polymerase is required to

30

- 50 -

specifically digest TaqMan probes between fluorophore and quencher moieties, causing increases in fluorescence emission in the presence of perfectly matched targets. Deep Vent and Stoffel fragment polymerases were employed in homogeneous amplification assays to test the ability of a NAT2 *4 F HyBeacon probe to detect target amplification in the absence of 5'-3'-exonuclease activity (figure 19). Reactions containing both types of polymerase did exhibit increases in fluorescence emission with matched templates throughout the course of amplification, whereas reactions containing mismatched template did not generate fluorescence increases. SNP discrimination may be achieved in 'real-time' and post-amplification formats with Deep Vent and Stoffel fragment polymerases. Therefore, these results indicate that the mechanism by which F HyBeacons detect DNA sequences by real-time PCR is distinct from that of the 5'-3'-exonuclease assay, relying on increases in fluorescence emission caused directly by probe hybridisation rather than enzymatic separation of fluorophore and quencher moieties.

(xiii) Quantitative PCR utilising HyBeacon probes.

The ability to monitor the 'real-time' progress of PCR amplification completely revolutionises the approaches by which PCR-based quantitation of DNA and RNA may be performed. In 'real-time' quantitative PCR experiments, reactions are characterised by the point in time during cycling when amplification of a PCR product is first detected (C_T - threshold cycle) rather than the amount of PCR product accumulated after a fixed number of cycles. The higher the starting copy number of the nucleic acid target, the sooner a significant increase in fluorescence is observed. The potential of HyBeacon probes to quantify target DNA in 'real-time' amplifications was examined using the 2D64B, 2D64C* and DdeFL1 F HyBeacons. Quantitative HyBeacon PCR analyses were performed with LightCycler and ABI 7700 instruments. Ranges of DNA standards (known concentrations of PCR product or genomic DNA) were

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employed as templates for homogeneous PCR amplification. The threshold cycle for each DNA standard was measured and the log DNA concentrations were plotted against C_T to generate 'straight line' standard curves. Threshold cycles obtained from samples containing 'unknown' concentrations of genomic DNA were plotted on the standard curve to calculate the concentration of DNA present in these reactions. The standard curves derived from HyBeacon quantitative PCRs were of very high quality with both LightCycler and ABI 7700 instruments, possessing correlation coefficients between 0.93 and 0.99 (figure 20). Calculation of DNA concentration from these standard curves was moderately accurate for the 'unknown' reactions tested, where calculated concentrations were in the correct order of magnitude. For example, 5.4×10^4 ng/ μ l, 700 ng/ μ l and 90 ng/ μ l 'unknown' samples had concentrations of 6.9×10^4 ng/ μ l, 1406 ng/ μ l and 115 ng/ μ l calculated from LightCycler standard curves respectively. Whereas, 285 ng/ μ l, 163 ng/ μ l and 53 ng/ μ l genomic samples were calculated as being 256 ng/ μ l, 137 ng/ μ l and 44 ng/ μ l with standard curves derived from the ABI 7700.

(xiv) *Detection and discrimination of target sequences without prior DNA extraction.*

Obtaining a genotype from a patient sample, such as blood or buccal swab, typically requires that genomic DNA be extracted prior to PCR amplification and downstream analysis. DNA extraction protocols may be time-consuming, laborious and expensive. Therefore, to reduce the duration and cost of HyBeacon analyses, direct PCR amplification from saliva DNA was performed, removing the requirement for genomic DNA extraction. Combined with the rapid thermal cycling conditions of the LightCycler, direct target amplification from saliva permits polymorphic sequences to be genotyped within 35-40 minutes.

Polymorphic NAT2 *4 and *5C sequences were amplified from 10 saliva samples and analysed with DdeFL1 and DdeFL1*4 HyBeacons,

which are fully complementary to *5C and *4 alleles respectively. Figures 21 and 22 illustrate the real-time PCR data and melt peaks derived from DdeFL1 and DdeFL1*4 hybridisation to DNA sequences amplified from *5C/*5C (sample 1), *4/*4 (sample 2) and *4/*5C (sample 3) genotypes.

5 Table 6 displays HyBeacon melting temperatures derived from DdeFL1 and DdeFL1*4 hybridisation to polymorphic *NAT2* sequences. The real-time PCR and *T_m* data permits an individual's genotype, with respect to the *5C polymorphism, to be determined. Of the 10 saliva samples analysed, 3 were classified as being homozygous for the *5C allele, 1 was

10 characterised as being homozygous for the *4 allele and 6 were found to be heterozygous. These genotypes, at the *NAT2* *5C gene locus, correlate with slow, fast and intermediate acetylation phenotypes respectively. To confirm the genotypes and phenotypes obtained from HyBeacon analysis of saliva samples, RFLP analysis was performed for saliva samples 1-3

15 (figure 23). A 179bp PCR product amplified from *4/*4 DNA contains a single DdeI restriction site, which upon digestion results in 121bp and 58bp fragments. The *5C polymorphism generates an additional DdeI restriction site, such that digestion of 179bp product amplified from *5C/*5C DNA results in 98bp, 58bp and 23bp fragments. Digestion of product amplified

20 from heterozygous saliva samples results in 121bp, 98bp, 58bp and 23bp fragments. Saliva samples 1-3 are typed as being homozygous *5C, homozygous *4 and heterozygous respectively by both RFLP and HyBeacon methodologies. Therefore, the data presented here demonstrates that reliable amplification, detection and discrimination of

25 polymorphic sequences may be performed without the need for purification of high quality DNA.

5 **Table 6.** T_m values derived from melting curve analysis of amplified NAT2 *4 and *5C sequences. The DdeFL1 and DdeFL1*4 HyBeacons are perfectly matched to *5C and *4 alleles respectively. The means and standard errors of matched and mismatched melt peaks are detailed for each saliva sample and for all samples collectively. NP indicates the absence of a particular peak in a given melting trace and '-' shows that the DdeFL1*4 assay was not performed for a particular saliva sample.

Saliva sample	DdeFL1 (mean °C ± SE)		DdeFL1*4 (mean °C ± SE)		Genotype	Associated acetylation phenotype
	T _m 1	T _m 2	T _m 1	T _m 2		
1	NP	53.8 ± 0.1	42.0 ± 0.3	NP	S1d/S1d	Slow
2	47.5 ± 0.1	NP	NP	52.1 ± 0.1	F1/F1	Fast
3	47.4 ± 0.1	54.1 ± 0.1	42.6 ± 0.1	52.4 ± 0.5	S1d/F1	Intermediate
4	47.9 ± 0.1	54.2 ± 0.1	-	-	S1d/F1	Intermediate
5	47.7 ± 0.1	54.1 ± 0.2	-	-	S1d/F1	Intermediate
6	NP	53.8 ± 0.2	42.3 ± 0.3	-	S1d/S1d	Slow
7	47.9 ± 0.3	54.1 ± 0.2	-	-	S1d/F1	Intermediate
8	47.9 ± 0.2	54.2 ± 0.1	-	-	S1d/F1	Intermediate
9	47.7 ± 0.0	54.1 ± 0.1	-	-	S1d/F1	Intermediate
10	NP	54.2 ± 0.1	-	-	S1d/S1d	Slow
Total	47.6 ± 0.1	54.1 ± 0.1	42.4 ± 0.1	52.3 ± 0.2	-	-

10 (xv) *Detection of RNA sequences*

The potential for the detection of RNA targets was assessed. Initially, a HyBeacon probe was designed to detect a NASBA (Nucleic Acid Sequence Based Amplification) RNA product. This product was not detected by the generation of HyBeacon melt peaks in melting curve analyses, possibly
 15 due to degradation of the RNA product. Therefore, oligonucleotide homologues consisting of DNA or RNA were synthesised to analyse the hybridisation of the HyBeacon probe. Initially, melting peaks were derived from the DNA target but not from the RNA oligonucleotide. It was not until the concentration of the RNA target was increased to 2µM that melt peaks,
 20 characteristic of probe hybridisation, were derived (data not shown). It was demonstrated that the melting temperature of HyBeacon/RNA duplexes are significantly reduced compared with HyBeacon/DNA duplexes, suggesting that hybridisation to RNA is considerably less stable than hybridisation to DNA. Therefore, unless high concentrations of RNA targets can be

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generated during analyses, HyBeacon probes may be unable to reliably detect them.

(xvi) *Mechanism of sequence detection*

- 5 Hybridisation of HyBeacon probes to complementary target DNA sequences results in significant alterations in the amount of fluorescence emission despite the absence of probe quencher moieties. Nucleotide residues, especially guanine, have been demonstrated to effect fluorescence emission through static and dynamic quenching mechanisms.
- 10 Therefore, quenching of HyBeacon fluorescence could potentially arise from the oligonucleotide component of the probe through base-dye stacking and electron transfer events. HyBeacon hybridisation to target sequences may alter the orientation of the fluorophore moiety relative to the oligonucleotide component, affecting the amount of electron transfer
- 15 between dye and base. Alternatively, changes in base-dye stacking resulting from duplex formation, e.g. intercalation of the fluorophore into the base stack, may alter the amount of fluorescence quenching. When HyBeacon probes hybridise to target DNA sequences, a conformation shift may relieve a small but detectable amount of the fluorescence quenching
- 20 imposed by the HyBeacon oligonucleotide. Reduced quenching results in an increase in the amount of fluorescence emission, permitting sequence detection and allele discrimination. To investigate the molecular mechanism by which HyBeacon probes function, fluorescence and u.v. spectroscopic techniques may be employed to analyse possible alterations
- 25 of quantum yield, fluorescence lifetime and emission wavelength occurring between single-stranded and duplex states.

Conclusions

- 30 Hybridisation beacons (HyBeacons) have been demonstrated to detect specific DNA sequences through the increases in fluorescence emission that are generated as a direct result of probe hybridisation to

complementary target sequences. The amount of fluorescence emission and the T_m of probe/target duplexes allow discrimination of SNPs in oligonucleotide and amplified PCR sequences. Results reported here demonstrate that HyBeacon assays permit the identification of homozygous and heterozygous samples using a single probe and that the use of multiple HyBeacon probes in a single tube/well assay has the potential for multiplex analysis. Furthermore, HyBeacons have been demonstrated to quantify DNA targets in 'real-time' PCR assays.

HyBeacon probes are an alternative to the commercial systems currently available (molecular beacons, Scorpions, FRET probes and TaqMan™ probes) for sequence detection, SNP discrimination and DNA quantification. Detection assays using HyBeacons are attractive due to their simple mode of action, lacking secondary structure and a requirement for an enzyme and their ability to identify heterozygous DNA using a single probe.

Molecular diagnostic assays may be performed by a homogeneous HyBeacon method (as described above), where target amplification and detection are performed in a single tube. Alternatively, robotic isolation of amplified target or solid phase immobilisation, followed by buffer replacement and addition of HyBeacon, may form a high throughput detection system. Differential hybridisation assays could be performed in microarray or macroarray formats, where either the probes or more preferably the targets are immobilised prior to HyBeacon melting analysis.

Two variants of the HyBeacon probe have been evaluated. Probes may contain both fluorophore and quencher moieties linked to internal nucleotide residues (F-Q HyBeacon) or may contain only the fluorophore component (F HyBeacon). Both variants have been demonstrated to reliably discriminate SNPs in homogeneous and heterogeneous formats. However, F HyBeacons have obvious advantages over the F-Q design:

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- At present, fluorophore and quencher moieties may only be positioned on T residues. Therefore, F HyBeacons are significantly more straightforward to design with reduced constraints, such that the number of residues separating fluorophore and quencher moieties and possible angular disposition effects do not need to be considered.
- Due to the absence of a quencher, F HyBeacons are less expensive to synthesise and assays require approximately five times less probe per reaction (less than 200nM) compared with F-Q probes.
- F HyBeacons have been demonstrated to have the potential to generate superior quality post-amplification melting curves in 'real-time' homogeneous assays.
- In contrast to the two F-Q probes required for heterozygote analysis, F HyBeacons have been demonstrated to identify heterozygous samples using a single probe.

The invention is not limited to the embodiments hereinbefore described which may be varied in construction and detail without departing from the spirit of the invention.

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CLAIMS

1. A hybridisation beacon which is an oligonucleotide having substantially no secondary structure and formed of nucleotide residues of which one is labelled with a reporter wherein the beacon includes a single reporter without an associated quencher.
5
2. The hybridisation beacon of claim 1, wherein the oligonucleotide has a sequence complementary to one allele of a known target polynucleotide which, optionally, has a known polymorphism/mutation.
10
3. The hybridisation beacon of claim 2, wherein the known polymorphism is a point mutation or a single base insertion or deletion.
15
4. The hybridisation beacon of claims 2 or 3, wherein the known polymorphism of the polynucleotide target is complementary to a nucleotide residue towards the centre of the hybridisation beacon molecule.
- 20 5. The hybridisation beacon of any one of claims 1 to 4, wherein the reporter-labelled nucleotide residue is positioned internally of the oligonucleotide.
6. The hybridisation beacon of any one of claims 1 to 5, wherein the reporter is a fluorophore.
25
7. A hybridisation beacon which is an oligonucleotide having substantially no secondary structure and formed of nucleotide residues of which one is labelled with a reporter and another is labelled with a quencher, with 1 to 15 nucleotide residues between the reporter - labelled nucleotide residue and the quencher – labelled nucleotide residue.
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8. The hybridisation beacon of any one of claims 1 to 7, when immobilised on a support.
- 5 9. An array of oligonucleotide probes immobilised at spaced locations on or within a support, wherein different oligonucleotide probes are different hybridisation beacons according to any one of claims 1 to 7.
- 10 10. A method of investigating a polynucleotide target having a known or suspected polymorphism, which method comprises providing a hybridisation beacon of any of claims 1-7, incubating the polynucleotide target with the hybridisation beacon to form a hybrid, the hybridisation beacon exhibiting a higher level of signal when in the form of the hybrid than when in single-stranded form, and observing the level of signal of the hybridisation beacon at a predetermined temperature, or over a range of
15 temperatures, near the melting temperature of the hybrid.
11. The method of claim 10, wherein the reporter is a fluorophore, and the signal whose level is observed is fluorescence.
- 20 12. The method of claims 10 or 11, wherein the method is used to detect, identify or quantitate the presence or the amount of target sequence present in a sample.
- 25 13. The method of any of claims 10 to 12, wherein the hybridisation beacon has a sequence complementary to one allele of the target polynucleotide.
14. The method of claim 13, wherein each of two or more
30 different hybridisation beacons has a sequence complementary to a different allele of the target polynucleotide.

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15. The method of any of claims 10 to 14, wherein the predetermined temperature, at which the level of signal of the hybridisation beacon is observed, is intermediate the melting temperatures of the hybrids
5 formed with the different alleles of the polynucleotide target.

16. The method of any of claims 1 to 14 wherein the range of temperatures encompass the melting temperature of the hybrid.

10 17. The method of any one of claims 10 to 14 and 17, wherein observation is made of the rate of change of the level of signal with change of temperature.

18. The method of any of claims 10 to 17, wherein amplification
15 of the polynucleotide target is performed in the presence of the hybridisation beacon.

19. The method of any one of claims 10 to 18, wherein the preferred polynucleotide target is a PCR amplimer.

20 20. The method of claims 18 or 19, wherein polynucleotide amplification is performed by Polymerase Chain Reaction (PCR), Ligase Chain Reaction (LCR), Strand Displacement Amplification (SDA), Transcription Mediated Amplification (TMA), Rolling Circle Amplification
25 (RCA) or Nucleic Acid Sequence Bases Amplification (NASBA).

21. The method of any of claims 18 to 20, wherein observation of the signal of the hybridisation beacon is made during the amplification of the polynucleotide target.

30

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22. The method of any of claims 10 to 21, where in hybridisation beacons are employed to detect and discriminate targets amplified from samples, such as saliva, without prior DNA extraction.

5 23. The method of any of claims 20 to 22, wherein the PCR reaction is an asymmetric amplification.

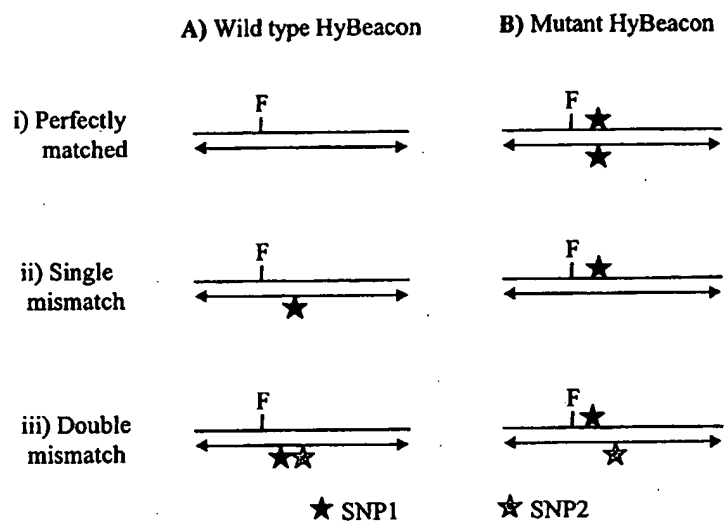
24. The method of any of claims 10 to 23 wherein the hybridisation beacon, the target sequence or both are immobilised on a
10 support.

25. Use of hybridisation beacons according to any of claims 1 to 7 in the differentiation between homozygous and heterozygous polynucleotide targets.

15

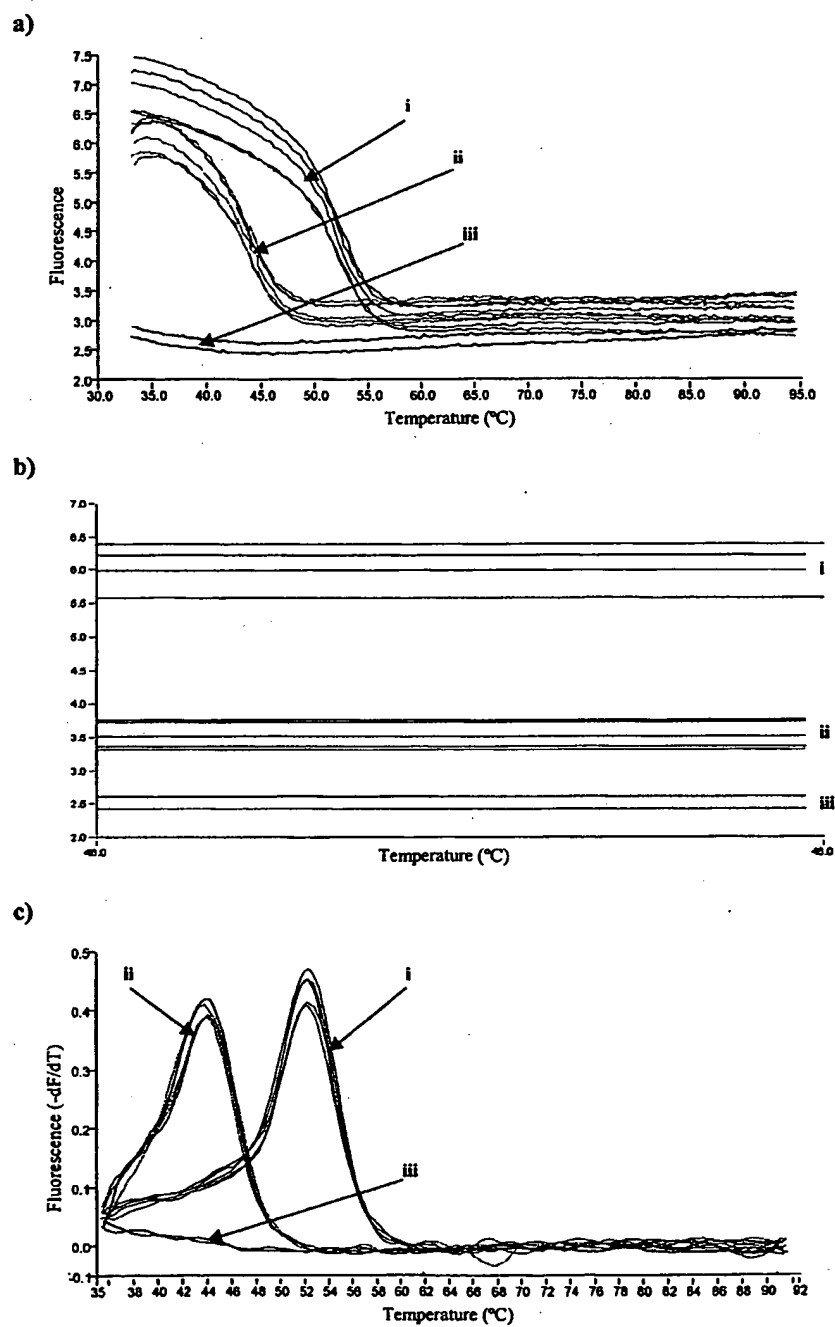
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Figure 1



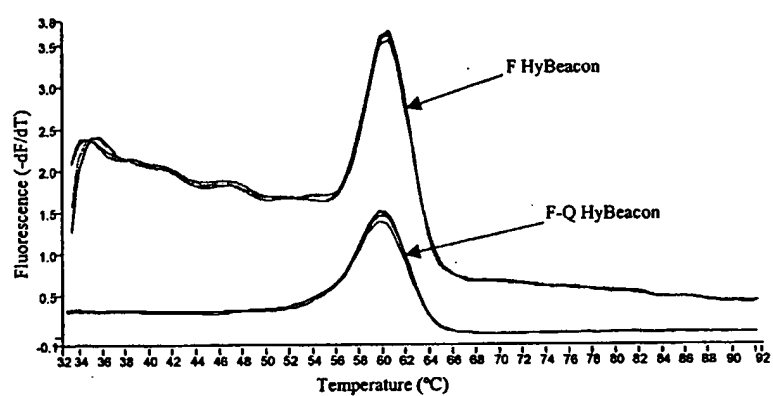
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Figure 2



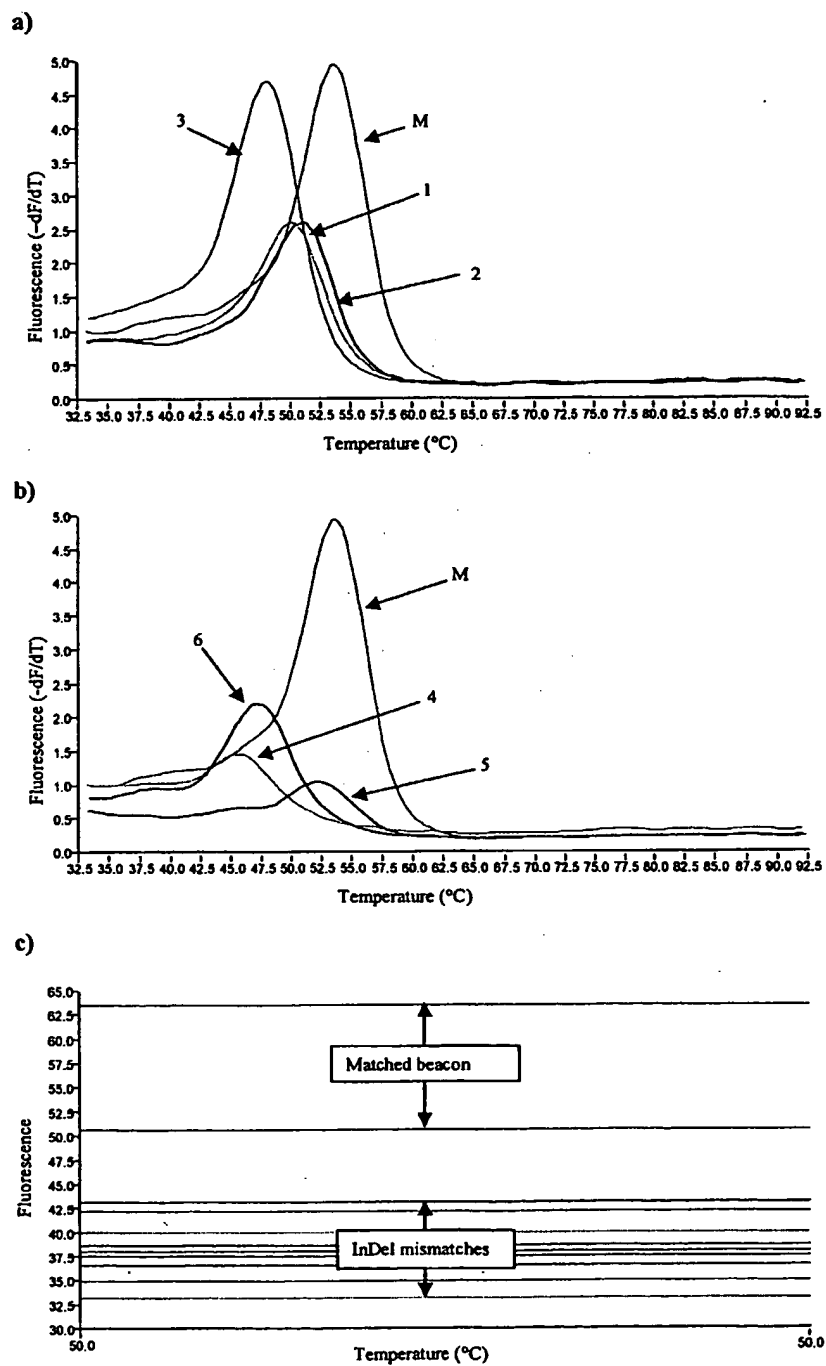
3/23

Figure 3



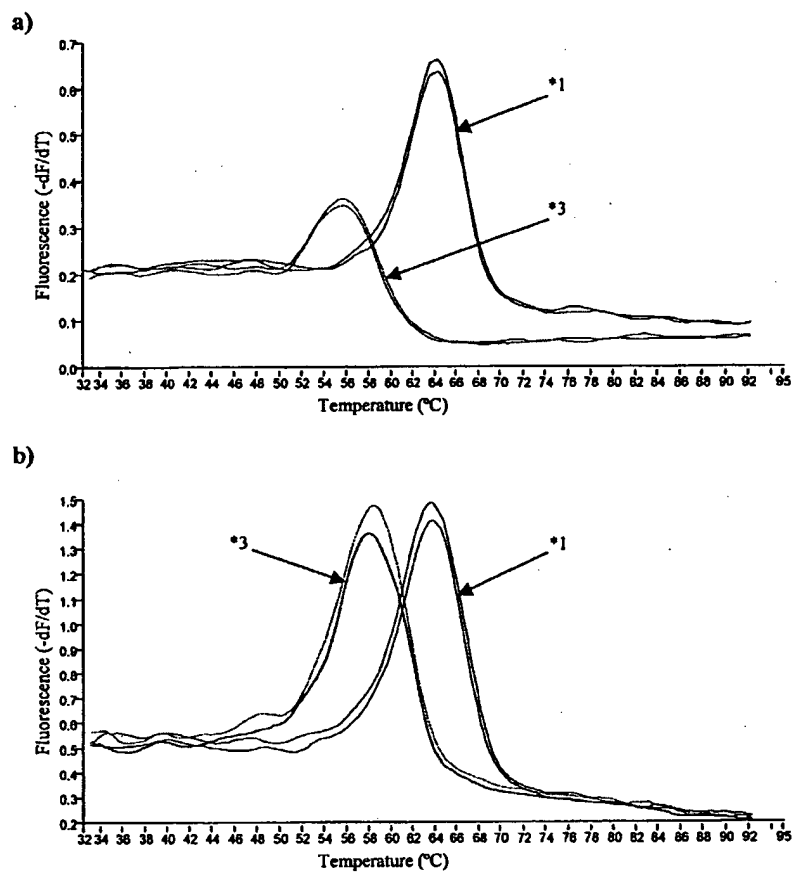
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Figure 4



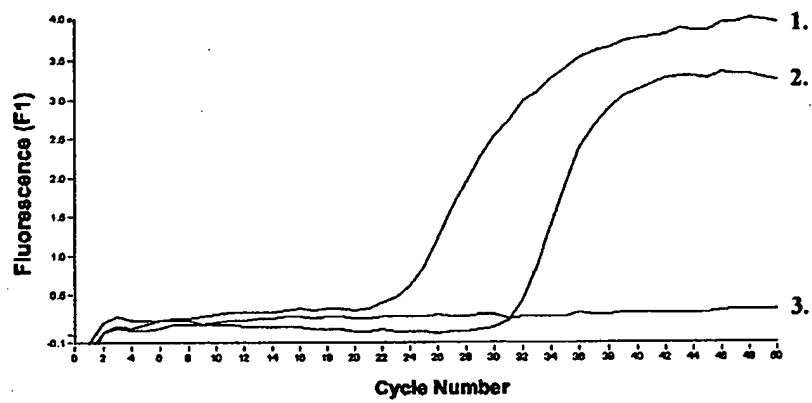
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Figure 5



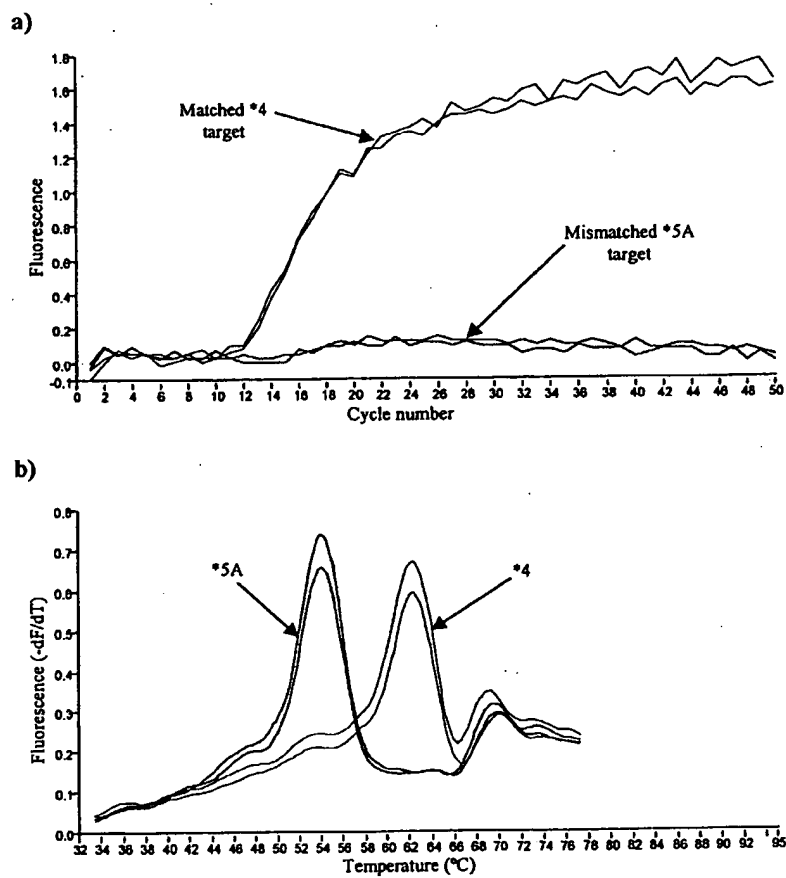
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Figure 6



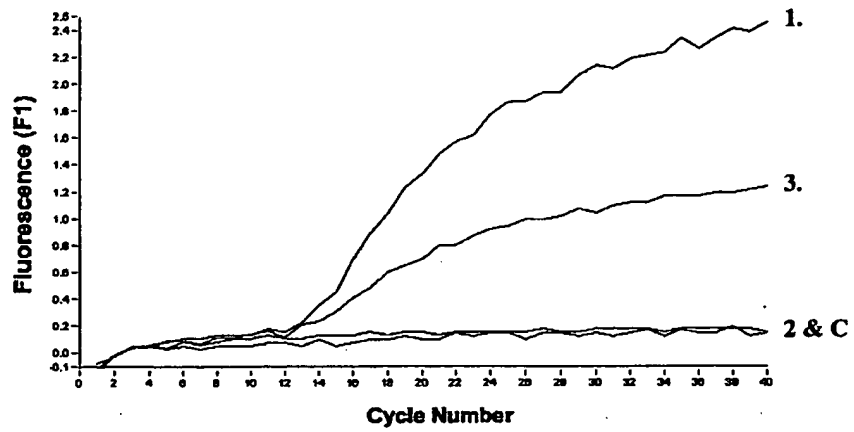
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Figure 7



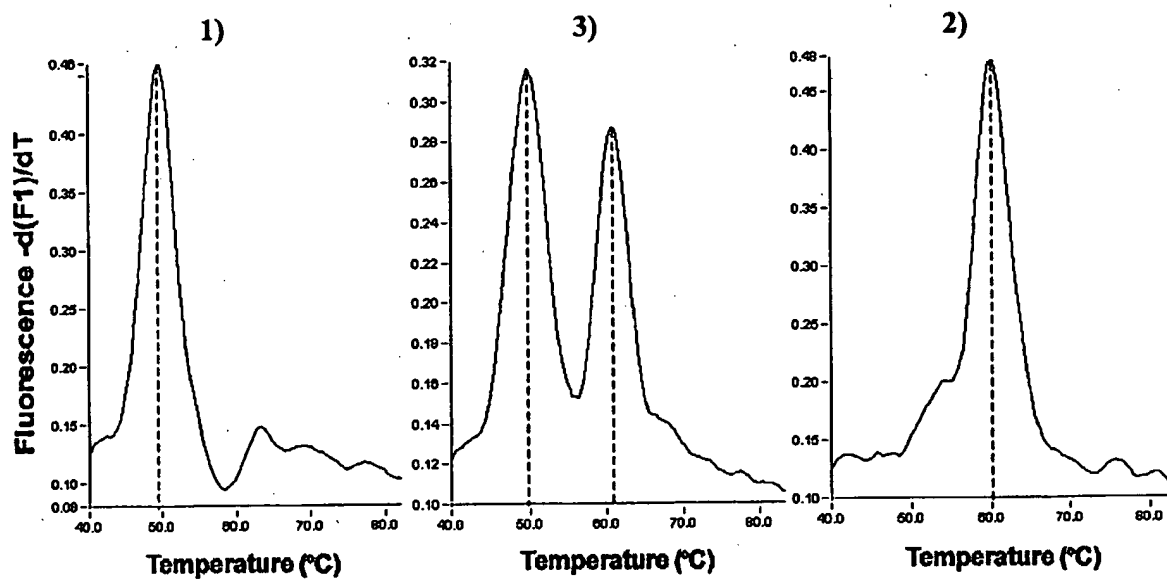
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Figure 8



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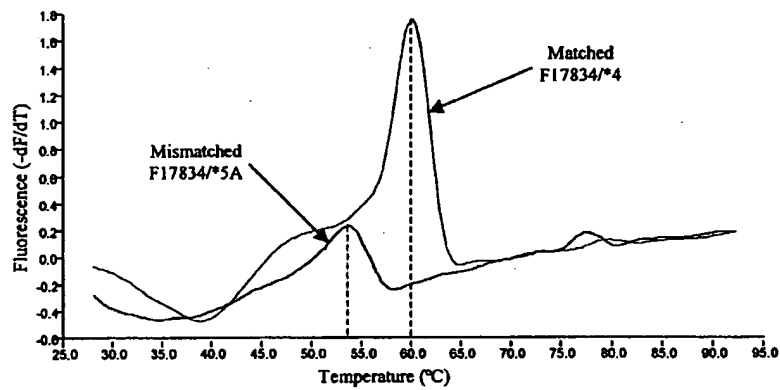
Figure 9



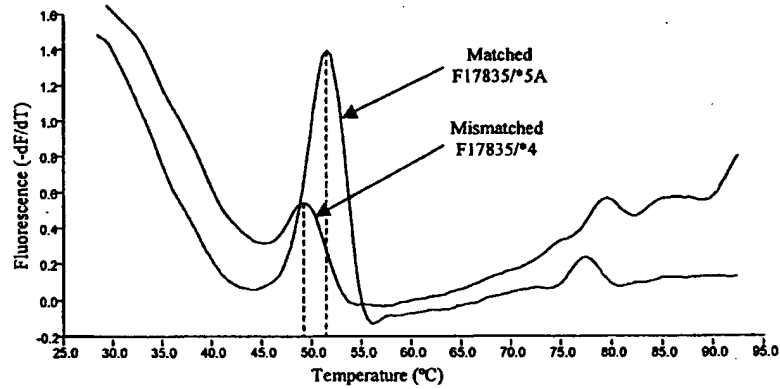
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Figure 10

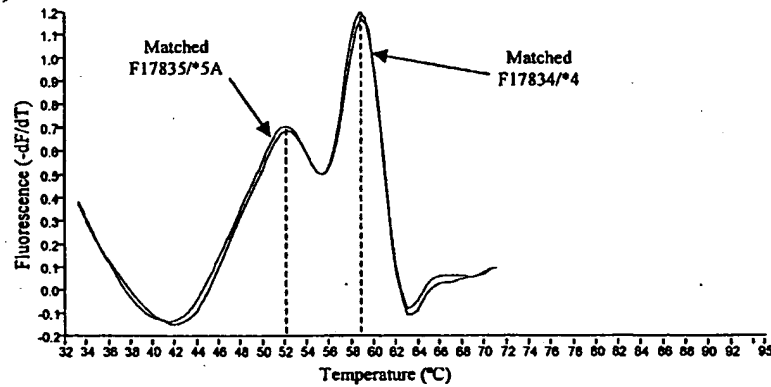
a)



b)



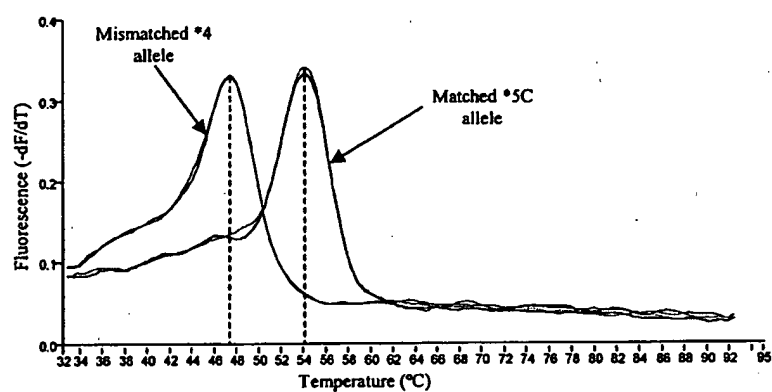
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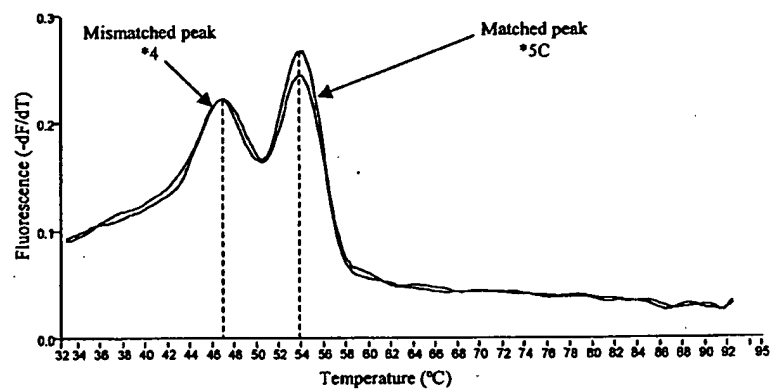
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Figure 11

a)

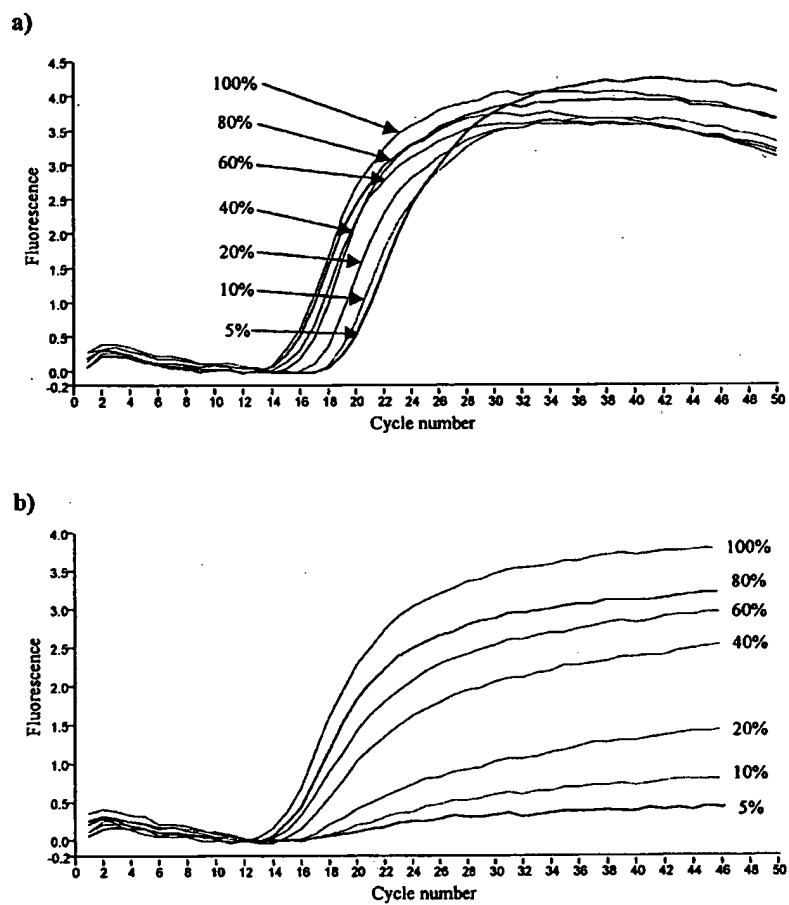


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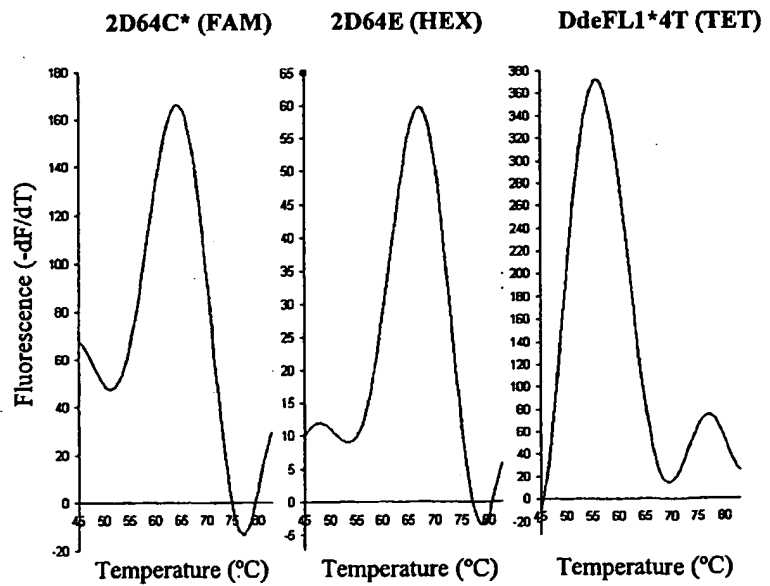
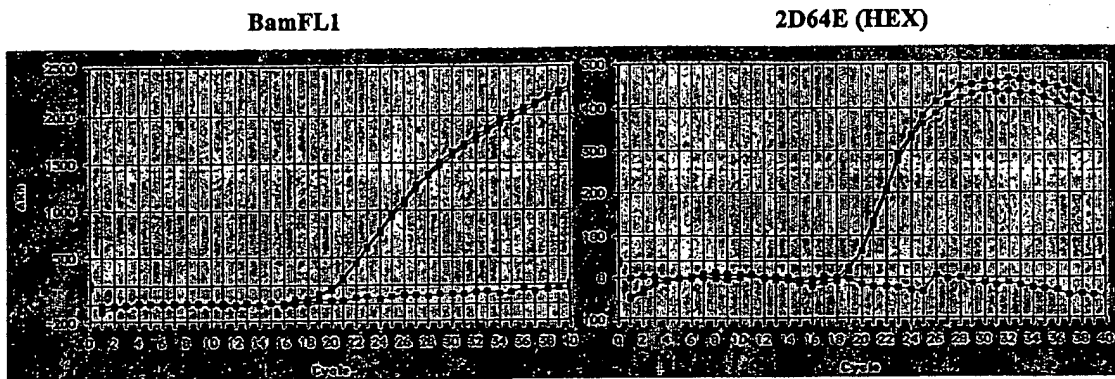
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Figure 12



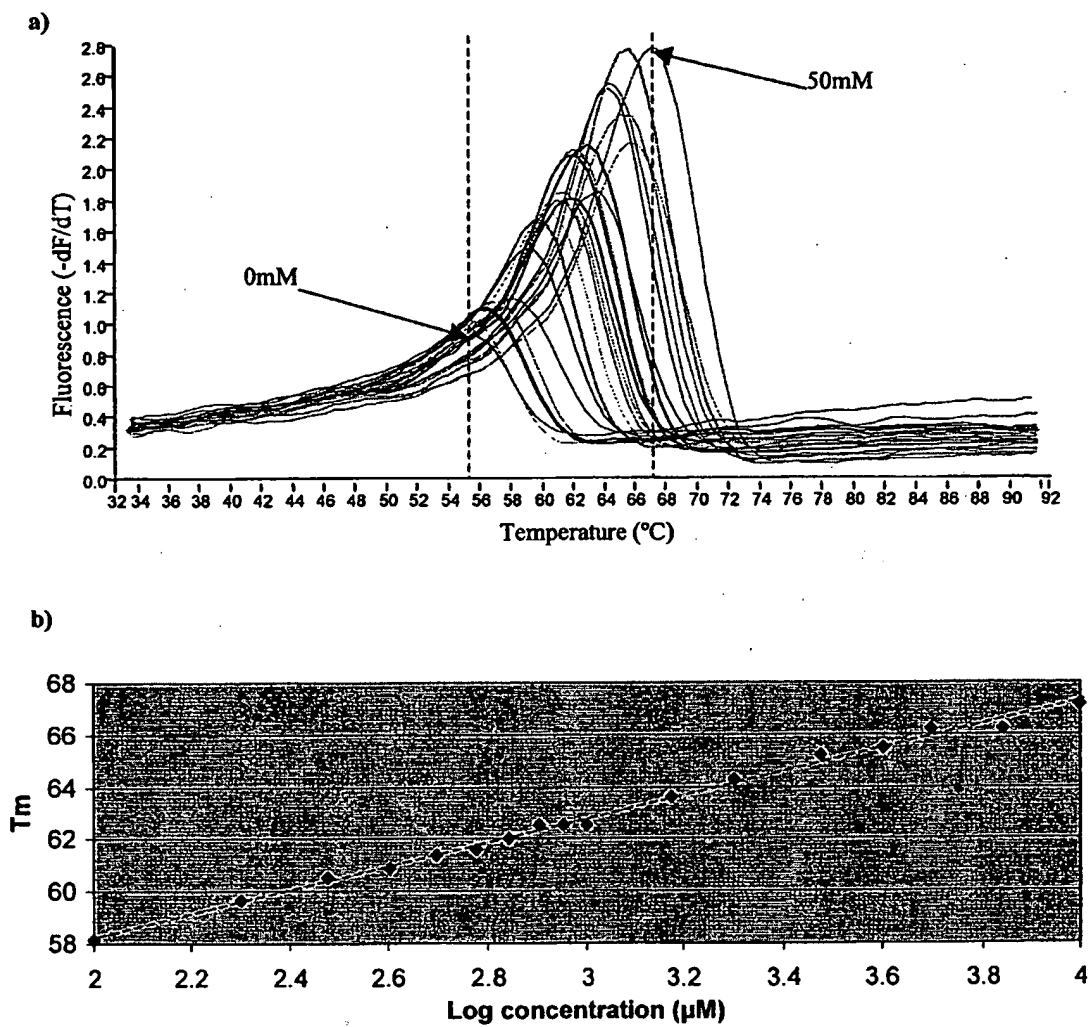
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Figure 13



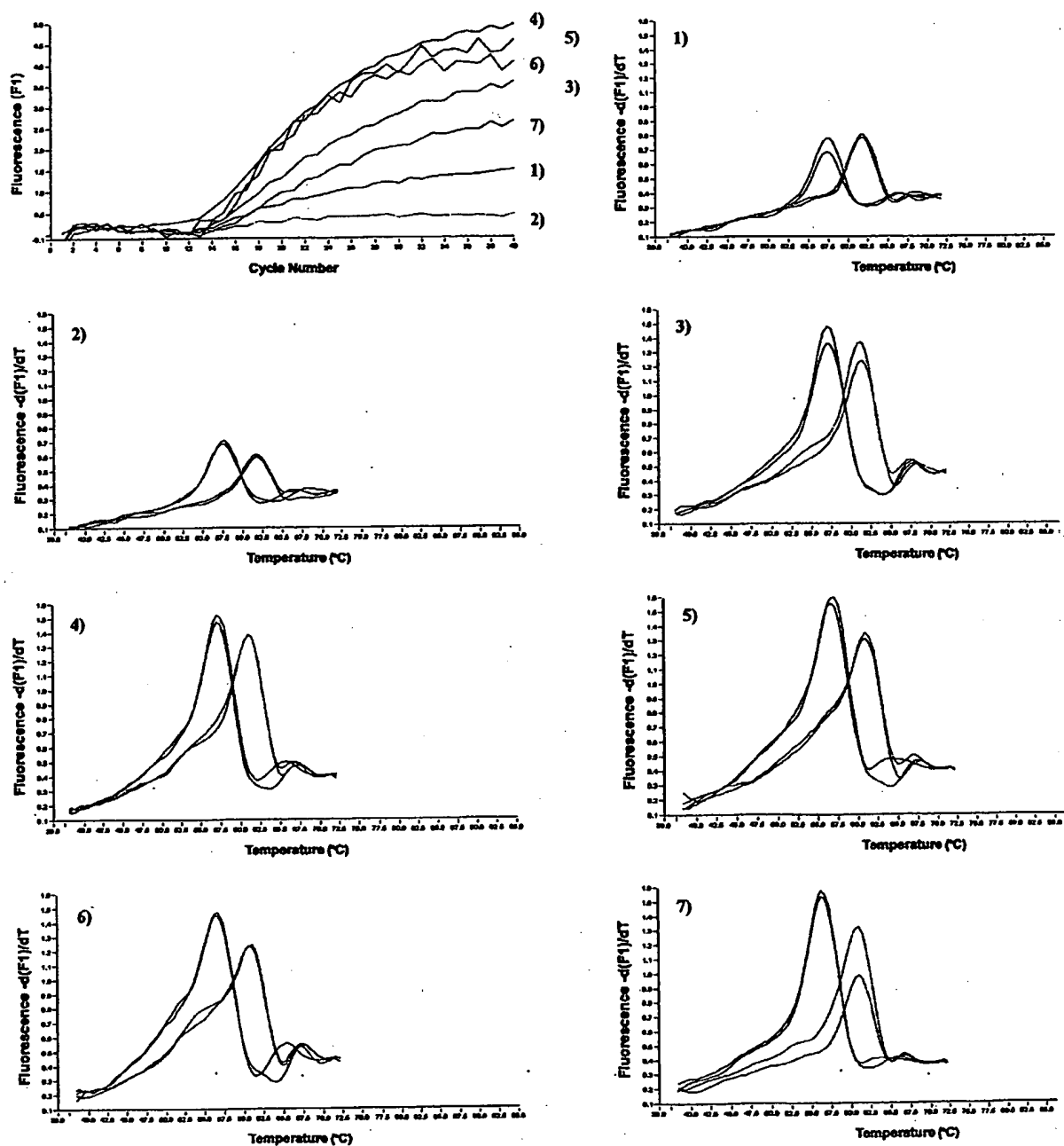
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Figure 14



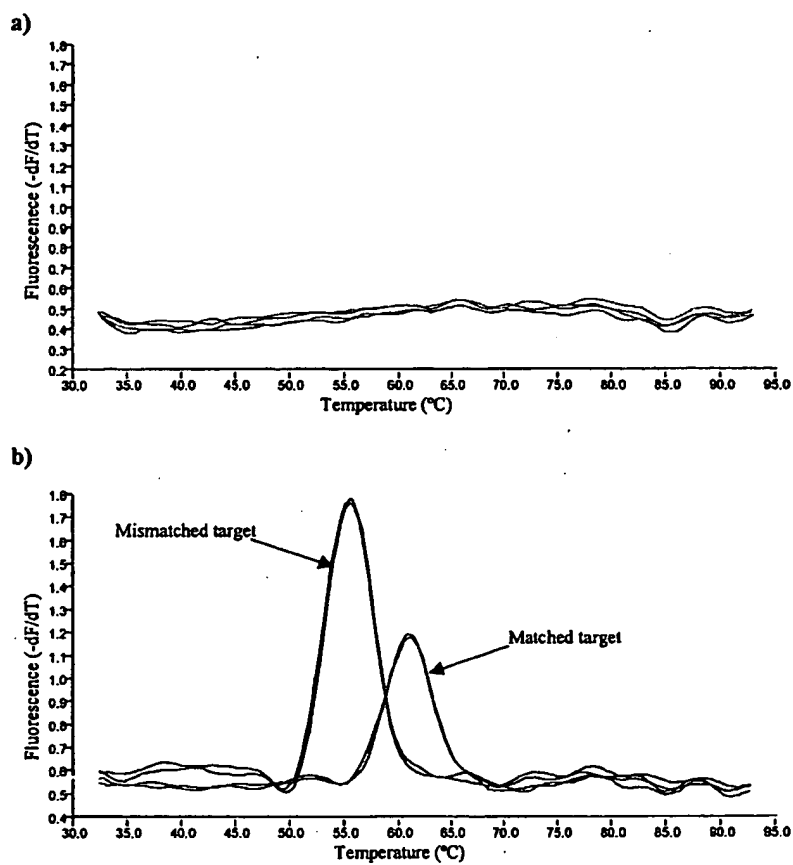
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Figure 15



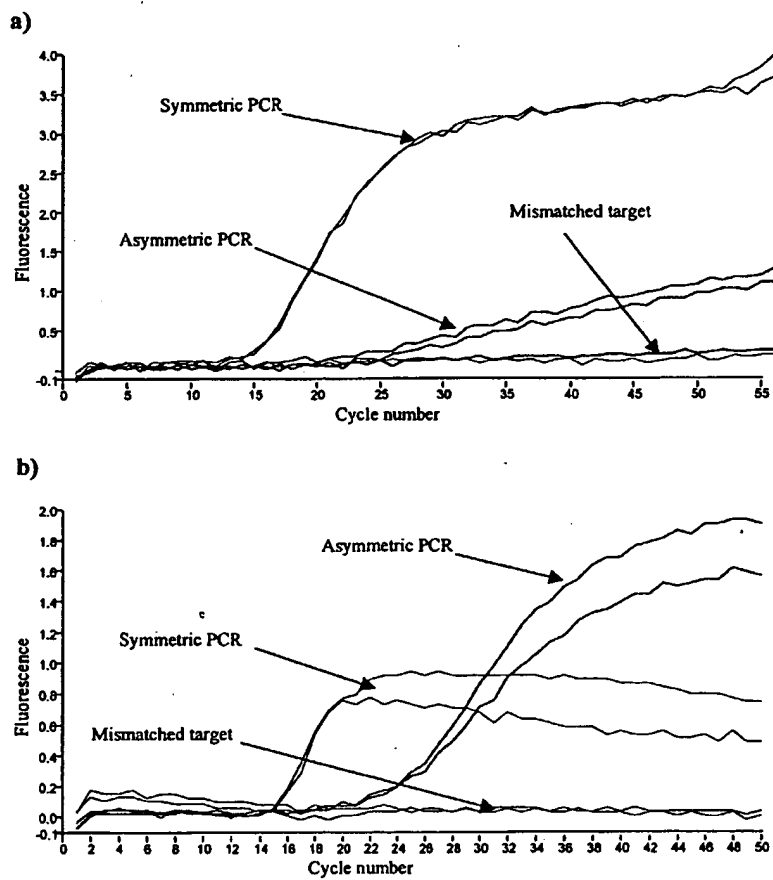
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Figure 16



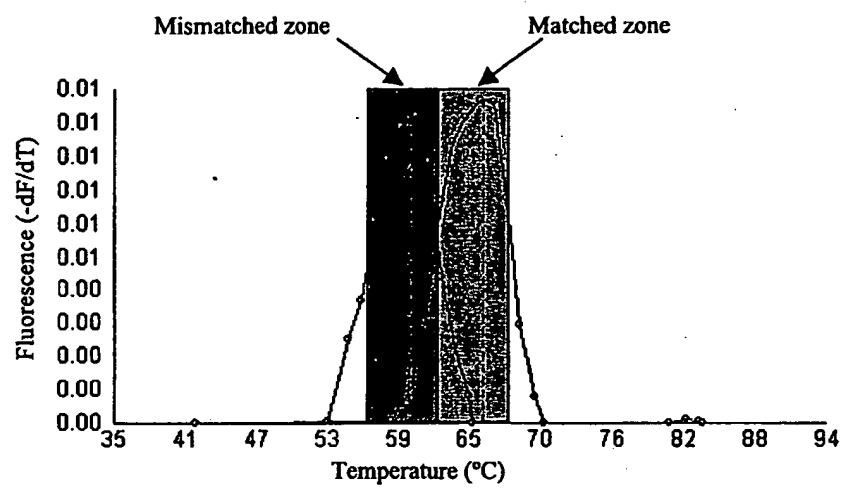
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Figure 17



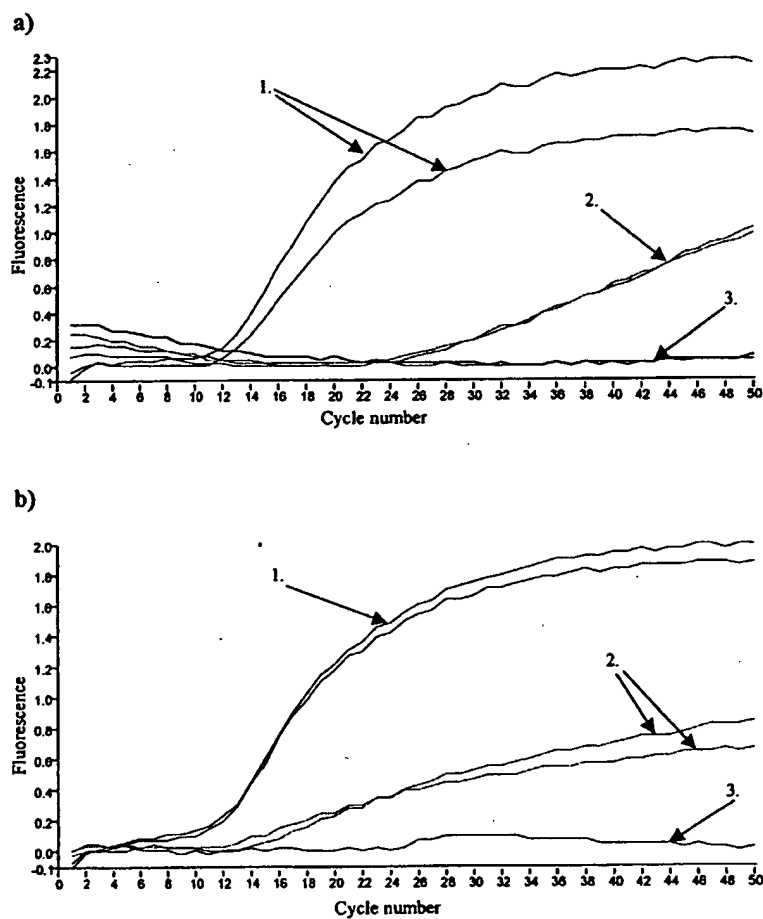
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Figure 18



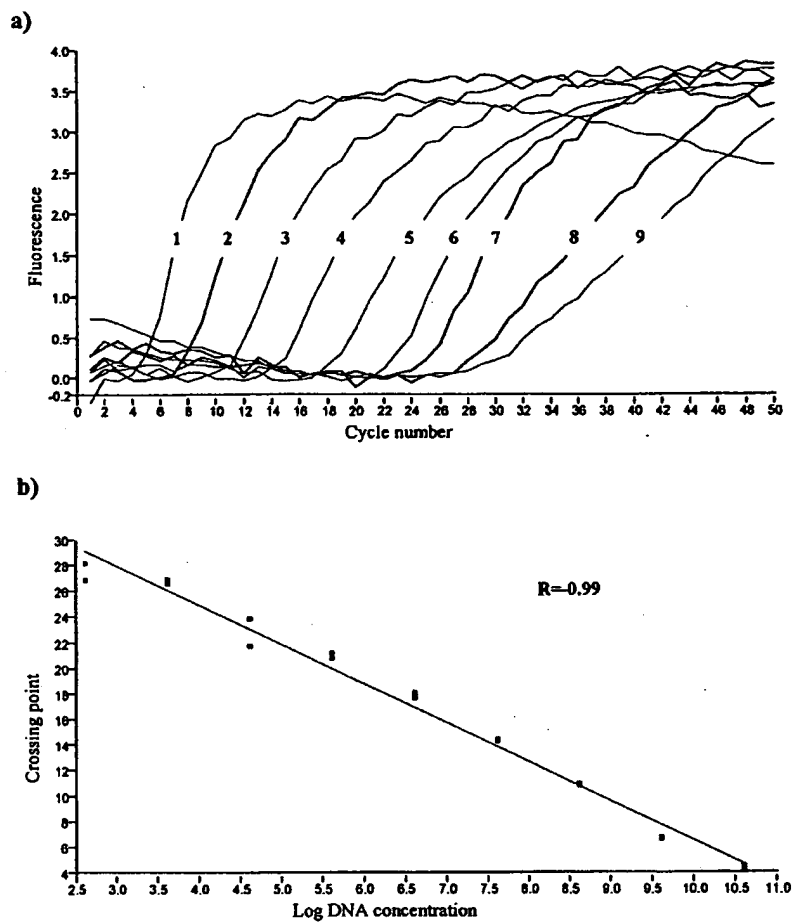
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Figure 19



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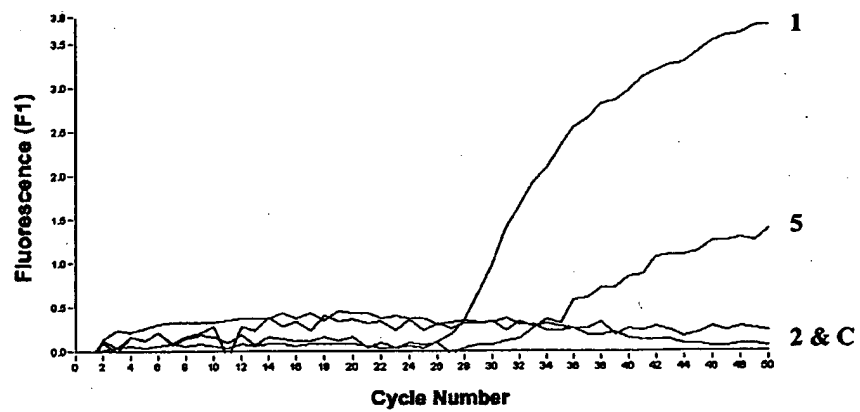
Figure 20



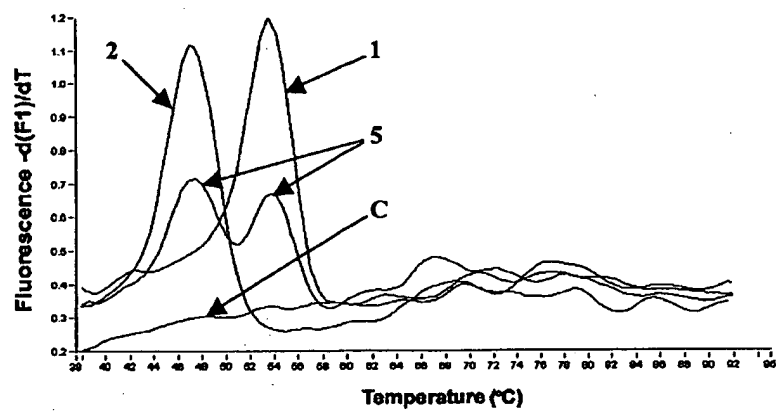
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Figure 21

a)

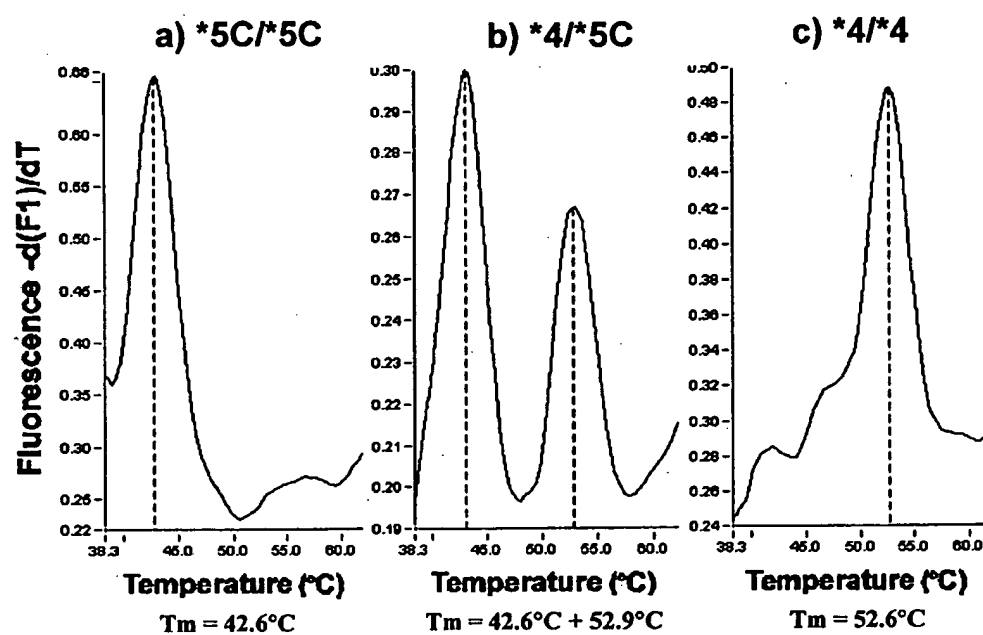


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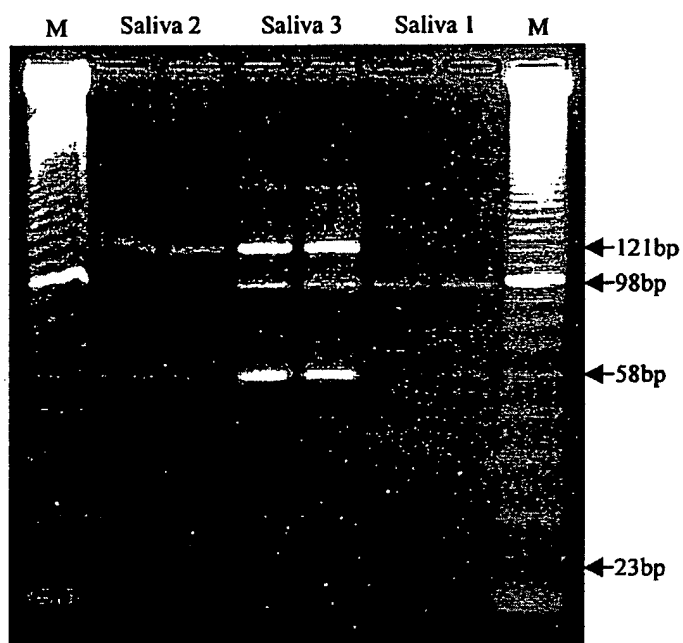


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Figure 22



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Figure 23

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LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX,
MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL,
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patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,
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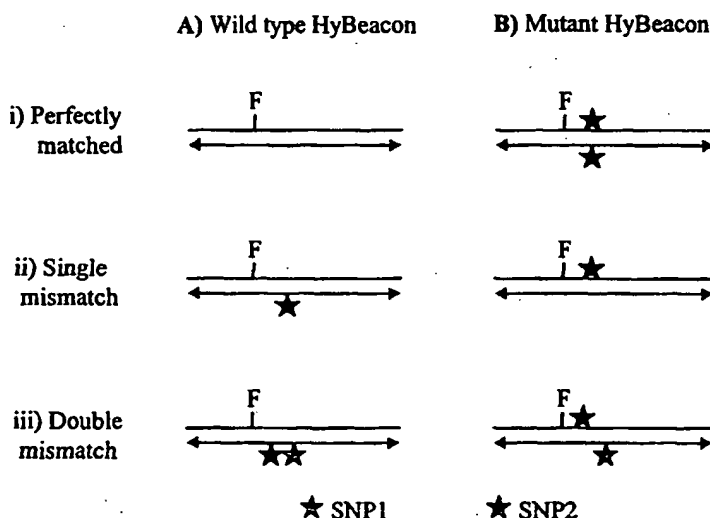
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(54) Title: HYBRIDISATION BEACON AND METHOD OF RAPID SEQUENCE DETECTION AND DISCRIMINATION



(57) Abstract: A method for detecting specific DNA sequences and discriminating single nucleotide polymorphisms (SNPs) using fluorescently labelled oligonucleotide probes is disclosed. Oligonucleotide probes are labelled with a reporter molecule preferentially attached to an internal nucleotide residue. The fluorescence emission of oligonucleotide probes varies significantly when in single-stranded and double-stranded states despite the absence of quencher moieties, allowing reliable detection of complementary DNA targets. The melting temperature of probe/target duplexes permits discrimination of targets that differ by as little as a single nucleotide residue, such that polymorphic targets may be discriminated by fluorescence quantitation and T_m . The

hybridisation probes of this invention have been demonstrated to accurately identify homozygous and heterozygous samples using a single fluorescent oligonucleotide and direct investigation of saliva with hybridisation probes permits ultra-rapid genotypic analysis within 35-40 minutes. Target detection and SNP discrimination assays have been achieved in homogeneous, heterogeneous, 'real-time' and solid-phase formats.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/01430

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 C12Q1/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 C12Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, BIOSIS, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 26093 A (US HEALTH ;HAWKINS MARY (US)) 18 June 1998 (1998-06-18)	1-6, 8-13, 18-24
Y	page 3, line 16 - line 25 page 7, line 27 -page 8, line 7 page 12, line 21 -page 13, line 24 page 25, line 1 - line 13 examples 1,2; tables 1-4 page 21, line 1 - line 26 page 22, line 17 -page 23, line 5 page 14, line 3 -page 15, line 15 ---	14-17,25
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☒ Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search

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Aguilera, M

INTERNATIONAL SEARCH REPORT

Intel onal Application No
PCT/GB 01/01430

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